(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 January 2001 (04.01.2001)

PCT

(10) International Publication Number
WO 01/01385 A1

(51) International Patent Classification[6]: G09G 3/36

(21) International Application Number: PCT/US99/14876

(22) International Filing Date: 29 June 1999 (29.06.1999)

(25) Filing Language: English

(26) Publication Language: English

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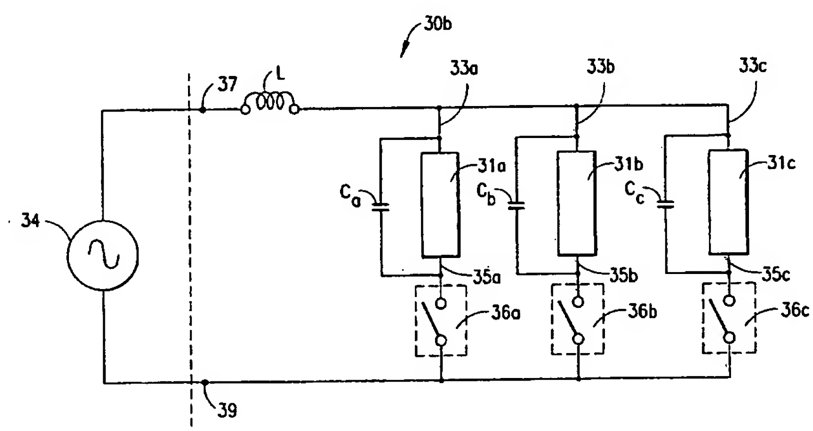
(81) Designated States (*national*): AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: AC POWERED LED CIRCUITS FOR TRAFFIC SIGNAL DISPLAYS



(57) Abstract: An LED array circuit (30b) includes a number of series connected LED pairs (32), each pair (32) including two parallel connected oppositely polarized LEDs. The array is coupled to a standard AC voltage source (34) in series with an inductor having Q>5 and a reactance which is equivalent to the resistance of a current limiting resistor. The use of an inductor in place of a resistor increases the efficiency of the array to approximately 80%. The efficiency of the array is increased even further by coupling a capacitor parallel to the array and by tuning the inductor and capacitor to the frequency of the AC voltage source (34). According to one embodiment of the invention, a single module is provided with a plurality of LED arrays (31a-31c), with each LED array (31a or 31b or 31c) having its own capacitor coupled in parallel thereto, and its own series coupled switch (36a or 36b or 36c). The module is coupled to and across the AC voltage source (34), with one node of the module coupled to the AC voltage source (34) by an inductor.

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AC POWERED LED CIRCUITS FOR TRAFFIC SIGNAL DISPLAYS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to light emitting diode arrays. More particularly, the invention relates to circuits incorporating light emitting diode arrays which are powered by an alternating current and which are advantageously used in traffic signal and other displays.

2. State of the Art

Modern traffic signal systems include two major components: the controller and the display (lights). The technology of modern traffic signal controllers is quite evolved and includes modern computer technology which incorporates traffic flow sensors, timers, and the like. Over the last seventy years, however, traffic signal displays have not changed significantly. The displays utilize high power broad spectrum incandescent bulbs with colored filters to produce the desired traffic signal color. It is well known that traffic signal displays are inefficient, as they consume large amounts of energy in order to produce a display which is bright enough to be seen in broad daylight. The inefficiency of the displays is due in part to the general inefficiency of incandescent bulbs, and is exacerbated by the fact that much of the light energy produced by the bulbs is wasted by filtering the light. Moreover, traffic signal displays require frequent maintenance. Incandescent bulbs have a relatively short life span, typically less than eight thousand hours, shorter still if switched on and off frequently and if constantly exposed to the elements; all of which are the case with traffic signals.

It is known in the art to use a light emitting diode (LED) array in lieu of incandescent bulbs in a traffic signal. Such arrays are disclosed, for example, in U.S. Patent Number 4,271,408 to Teshima et al., U.S. Patent Number 4,298,869 to Okuno, and U.S. Patent Number 4,954,822 to Borenstein, the complete disclosures of which are hereby incorporated herein by reference. An LED array can provide many advantages when used in lieu of an incandescent bulb. The primary advantages are that an LED array is much more efficient than an incandescent bulb and requires little or no maintenance. In most cases, an LED array will consume about one tenth the power that a filtered incandescent bulb will consume to produce the same light output. The life cycle costs of a traffic signal using an LED array in lieu of an incandescent bulb is also significantly reduced since incandescent bulbs used in traffic signals typically must be replaced once or twice a year. A well designed LED array could be expected to function for more than twenty years before requiring replacement. Another, less apparent advantage is that a single array can be used to display many different illuminated symbols such

as international symbols for turn only, do not enter, walk, don't walk, etc. The LED array is more resistant to the elements and is more mechanically durable than an incandescent bulb. It is also possible to achieve a higher flashing rate with an LED array than with an incandescent bulb. It is known in industrial psychology that certain high flashing rates are more apt to draw attention than other slower flashing rates. In addition, an LED array does not require a light reflector like the relatively large parabolical reflectors used with incandescent bulbs. The elimination of the reflector is an advantage because during certain seasons at certain times of day, sunlight can be reflected off the reflector in an incandescent bulb traffic signal and cause a confusing display. Yet another advantage of an LED array is that, if it is properly arranged, when faults develop in the array, the entire array need not fail.

Despite all of the advantages of using LED arrays in traffic signal displays, there are several concerns which have prevented their widespread adoption. The first and perhaps the most significant concern is that an LED array is not easily retro-fitted to an existing traffic signal. This is primarily because existing incandescent displays operate with a "standard" 120 volt 60 Hz AC power supply. LEDs require a DC current of approximately 5 to 20 milliamps and a forward operating voltage of between 1.5 to 2.5 volts depending on the wavelength of the emitted light and the semiconductor material used. Another reason why retro-fitting is difficult is because the "standard" traffic signal housings are designed to accept a "standard" incandescent bulb. These issues have been addressed in the art. As shown in prior art Figure 1, an arrangement which has been proposed by Borenstein, supra., uses a step down isolation transformer 10 with a center tapped full-wave rectifier 12 to drive an array of LEDs 14 which are connected in parallel. Although Borenstein does not specify exactly how many LEDs are to be used, a typical traffic signal display will require at least between twenty and eighty LEDs. Assuming that fifty LEDs are used with Borenstein's power supply, it is difficult to imagine that an efficiency of more than 50% could be achieved. Moreover, a most common LED failure mode is a short where the LED becomes a short circuit. If the LEDs are arranged in parallel as taught by Borenstein, a short fault in one LED will disable the entire array.

As shown in prior art Figure 2, a simpler arrangement which has been proposed by Teshima et al., supra., uses a rectifier bridge 16 to convert the AC power supply to pulsating DC and an array of sixty-two 1.6 volt LEDs 18 in series with a resistor 20. A smoothing capacitor 22 is connected in parallel with the array for absorbing ripple components of the power supply. Unfortunately, the rectifier circuit adds expense to the system and makes it less reliable. The resistor wastes energy and lowers the efficiency of the system. While Teshima et al. suggests that the rectifier can be eliminated by using pairs of oppositely polarized LEDs connected in series through a protective resistor, little information is given about this arrangement.

A simpler solution has been proposed by Okuno, supra., which is shown in prior art Figure 3. Okuno avoids the use of a rectifier bridge by providing an array of LEDs 24 which are connected in series and polarized in one direction and an array of LEDs 26 which are connected in series and polarized in the opposite direction. The two arrays 24 and 26 are connected in parallel so that a respective array is illuminated during each half cycle of the AC power supply. According to Okuno, however, a current limiting resistor 28 (a generator resistor) must be connected in series with the arrays. Assuming each array 24 and 26 includes twenty-five LEDs, the value of the resistor 28 should be approximately 3300 ohms to produce the desired average LED current. Since approximately 70% of the line voltage is dropped across the resistor 28, the resistor is the dominant factor in determining the LED current and energy is wasted by the resistor. In this example, the arrangement has an efficiency of only about 35% and the LED current has a range of ±25%. If a greater number of LEDs were used, the efficiency would increase, but the current range would widen.

Recently, committees have been formed to study the critical characteristics of LED arrays used in traffic displays and to make recommendations about these characteristics. See, e.g., Interim LED Purchase Specifications of the Institute of Transportation Engineers, Part 2, July 1998. One of the characteristics of LED arrays is the power factor (a value between zero and 1) and it has been recommended that the power factor be greater than 0.9. Another characteristic is total harmonic distortion (THD-F) which is recommended to be less than 20%. The ratio of peak to average current is indicative of the number of lumens obtained per watt of power. A low peak to average current is more efficient. Current regulation is also important in LED arrays as the line voltage (nominally 110-120 in the U.S.) normally fluctuates. One (US) standards committee recommends that current be regulated for voltage fluctuations between 80 and 134 volts. Some LEDs, especially red LEDs are sensitive to temperature and increase in brightness when ambient temperature drops. Therefore, many committees recommend that the circuits controlling traffic LEDs provide for temperature compensation. For LED traffic signals, it is also important that the LED array be tolerant to the failure of individual LEDs. Although the MTBF (mean time between failure) for an individual LED is greater than thirty years, it is quite likely that a single LED in an LED array having several hundred LEDs will fail in a shorter time. In particular, failure of an individual LED in an array should not cause more than 20% light loss. Whether an LED fails by shorting or by opening is another issue to be addressed.

Finally, some committees have expressed concern that LED arrays might interfere with other traffic control devices. In particular, some emergency vehicles are equipped with a light transmitter which modulates light in a manner similar to a TV remote control. Traffic signals are equipped with a light receiver so that the traffic signal can be controlled by an approaching

emergency vehicle. Since AC powered LED arrays of the type shown in prior art Figure 3 (self full wave rectifying) have a light output with a main frequency component of 120Hz (twice line frequency), there is some concern that this modulation will interfere with emergency vehicle remote traffic signal control.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a circuit incorporating an AC line powered LED array which is suitable for retro-fitting in an existing traffic signal display.

It is also an object of the invention to provide an AC line powered LED array circuit which does not require a rectifier bridge or a transformer.

It is another object of the invention to provide an AC line powered LED array circuit which has enhanced efficiency and does not use a current limiting resistance.

It is a further object of the invention to provide a highly efficient, low cost AC powered LED array circuit for use in traffic signal and other displays.

It is also an object of the invention to provide an AC line powered LED array having a large number of LEDs connected in series so that the cumulative voltage across the array may be comparable to or greater than an AC line voltage.

It is another object of the invention to provide an AC line powered LED array circuit which provides a relatively constant current through the LED array regardless of the type or number of LEDs in the array.

It is a further object of the invention to provide an AC line powered LED array and circuit which is highly fault tolerant.

It is still another object of the invention to provide AC line powered LED display which is compatible with existing traffic signal controllers.

It is also an object of the invention to provide an LED array and circuit which has a power factor greater than 0.9.

It is another object of the invention to provide an LED array and circuit which has a total harmonic distortion less than 20%.

It is a further object of the invention to provide an LED array and circuit which has a low peak to average current ratio.

It is still another object of the invention to provide an LED array and circuit which has current regulation for voltage variations from 80-134 volts.

It is also an object of the invention to provide an LED array and circuit which has a relatively constant light output regardless of ambient temperature.

It is another object of the invention to provide an LED array and circuit which is tolerant to the failure of individual LEDs.

It is a further object of the invention to provide an LED array and circuit which tolerates individual LED failures regardless of whether the failure is a short failure or an open failure.

It is still another object of the invention to provide an LED array and circuit which will not interfere with emergency vehicle remote control of traffic signals.

In accord with these objects which will be discussed in detail below, the LED array circuit of the present invention includes a number of series connected LED pairs, each pair including two parallel connected oppositely polarized LEDs, which are coupled to a standard AC voltage source by an inductor which is arranged in series between the AC voltage source and the LED array. The inductor is preferably provided with a Q>5 and a reactance which is equivalent to the resistance of a current generator or current limiting resistor. The use of an inductor in place of a resistor increases the efficiency of the array circuit to approximately 80% if the inductor is properly chosen. The efficiency of the array circuit is increased even further by coupling a capacitor in parallel to the array, thereby generating an impedance converter which converts an AC voltage source into a high impedance AC current source. By tuning the inductor and capacitor of the impedance converter to the frequency of the AC voltage source, the efficiency of the array is greater than 80%. Moreover, when the capacitor is included in the circuit, the power factor of the circuit is improved, non-linearity of the circuit is diluted, the impedance of the source is increased, and the LED array may include a large number of LEDs (e.g., forty pairs or more). In fact, so many LEDs may be included in the array such that the voltage drop across the array is greater than the AC line peak voltage itself.

According to a preferred embodiment of the invention, the LED array and circuit are mounted on a circuit board which is connected by spacers to a clear circular disk. The disk is

dimensioned to take the place of a standard traffic signal filter/lens. This embodiment is retro-fitted to an existing traffic signal by removing the bulb, reflector, and filter/lens from the traffic signal and mounting the clear circular disk in place of the filter. Alternatively, and in accord with another embodiment of the invention, a single retro-fittable unit is provided wherein an inductor, a capacitor, and an array of LEDs are contained in a housing having substantially the same size and shape as a standard incandescent bulb used in a traffic signal display. According to yet another embodiment of the invention, a plurality of individually switched arrays are contained in a single module where a first terminal of each array is coupled to a common point which is series connected through a single inductor to the AC voltage source, and a separate capacitor is coupled parallel to each array. The second terminal of each array is coupled through a respective individual switch to the AC voltage source. The second embodiment provides a module for several independently operable mutually exclusive displays.

Other embodiments of the invention include circuits which have improved power factors, LED arrays which tolerate the failure of individual arrays regardless of whether the failure is a short or open, circuits which compensate for the effects of temperature on LED luminance, circuits which regulate the current through the LED array as line voltage varies, circuits which balance the peak to average current ratio through the LED arrays, circuits which minimize harmonic distortion, and circuits which minimize the possibility of interference with emergency remote control of traffic signals. Further, according to the invention, circuits are provided for switching the current applied to LED arrays according to a plurality of parameters such as ambient temperature, ambient light, voltage, etc.

Additional objects and advantages of the invention will become apparent to those skilled in the art upon reference to the detailed description taken in conjunction with the provided figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of a prior art LED array circuit using a transformed and rectified power supply with LEDs coupled in parallel;

Figure 2 is a schematic diagram of a prior art LED array circuit using a filtered and rectified power supply with LEDs coupled in series with a current limiting resistor;

Figure 3 is a schematic diagram of a prior art LED array circuit with oppositely polarized series connected LEDs coupled in series with a current limiting resistor;

Figure 4 is a schematic diagram of a first embodiment of an LED array circuit according to the invention;

Figure 5 is a schematic diagram of a second embodiment of an LED array circuit according to the invention;

Figure 6 is a partially transparent side elevation view of a housing for the LED array circuit of Figure 5 which is adapted for retro-fitting in an existing traffic signal display;

Figure 7 is a cross sectional schematic view of a prior art traffic signal display having an incandescent bulb, a reflector, and a colored filter/lens;

Figure 8 is a side elevation schematic view of an LED array according to the invention mounted on a circular disk for retro-fitting in an existing traffic signal display;

Figure 9 is a cross sectional view similar to Figure 7 showing the LED array of Figure 8 installed in an existing traffic signal display;

Figure 10 is a schematic diagram of a third embodiment of an LED array circuit according to the invention;

Figure 11 is a schematic diagram of an LED array circuit similar to Figure 4 but having a higher power factor than other embodiments;

Figure 12 is a schematic diagram of a portion of an LED array which is protected against the failure of individual LEDs;

Figure 13 is a schematic diagram of a series circuit for temperature compensation;

Figure 14 is a schematic diagram of a series circuit for current regulation;

Figure 15 is a schematic diagram of an enhanced series circuit for current regulation and balancing;

Figure 16 is a schematic diagram of a circuit for temperature compensation, current regulation, and balancing;

Figure 17 is a schematic diagram of an LED array circuit similar to Figure 5 but having a higher power factor;

Figure 18 is a schematic diagram similar to Figure 5 but with temperature compensation;

Figure 19 is a schematic diagram similar to Figure 5 but which provides higher current and lower voltage for parallel LED arrays;

Figure 20 is a schematic diagram of a series LED array with a full wave rectifier and filter capacitor for use with the L-C circuit power supply according to the invention;

Figure 21 is a schematic diagram similar to Figure 20 but showing groups of LEDs protected against the failure of individual LEDs;

Figure 22 is a schematic diagram similar to Figure 21 but with a circuit for temperature compensation and current regulation;

Figure 23 is a schematic diagram of a circuit including several series LED arrays coupled to each other in parallel, each having a current sharing impedance;

Figure 24 is a schematic diagram of a current sharing impedance for use in the circuit of Figure 23;

Figure 25 is a schematic diagram of a current sharing impedance for use in the circuit of Figure 23;

Figure 26 is a schematic diagram of dual series LED arrays having an electronic balancing circuit;

Figure 27 is a schematic diagram similar to Figure 26 but with a circuit for temperature compensation and current regulation;

Figure 28 is a schematic diagram similar to Figure 5 but with the locations of the inductor and capacitor interchanged;

Figure 29 is a schematic diagram similar to Figure 28 but with a tapped inductor;

Figure 30 is a schematic diagram of a circuit for switching a pair of LED arrays to provide a brighter or dimmer output;

Figure 31 is a schematic diagram of a circuit for automatically switching the circuit of Figure 30;

Figure 32 is a schematic diagram of a lossless resonant synchronous boost regulator circuit; and

Figure 33 is a schematic diagram of an LED array circuit and a separate switching circuit for controlling the light output of the array according to a plurality of parameters.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to Figure 4, a first embodiment of an LED array circuit 30 according to the invention includes an array of LEDs 31 arranged as a plurality of LED pairs 32, and an inductor L. The LED pairs 32 each include two parallel coupled LEDs 32a, 32b which are oppositely polarized. The LED pairs 32 are coupled to each other in series to form the LED array 31. A first terminal or node 33 of the array is coupled to an AC voltage source 34 through the series connected inductor L, with the second terminal or node 35 of the array 31 coupled to the AC voltage source through a switch 36. It will be appreciated that the switch 36 shown in Figure 4 is merely representative of some type of switching circuit and in practice will likely be part of a traffic signal controller. It will also be understood that the connection of the circuit 30 to the AC voltage source 34 is preferably a removable connection as represented in Figure 4 by removable couplings 37 and 39. According to the invention, the inductor L is chosen to have a reactance equivalent to the resistance of a current generator or current limiting resistor and to have $Q>5$. The use of inductor L with the array 30 produces an efficiency of about 80% and achieves all of the advantages of LED arrays without suffering the disadvantages of the current limiting resistor of the prior art.

It will be appreciated that during one half cycle of the AC voltage source, one of the LEDs in each pair will light and during the other half cycle, the other LED in each pair will light. One of the advantages of arranging the LEDs as shown (i.e. in parallel oppositely polarized pairs which are series connected) is that if an LED faults either closed (short) or open, only that LED or one LED pair will be disabled. That is, if an LED shorts, all of the remaining LEDs will continue to function except for the one which is paired with the shorted LED and which will be shorted thereby. If, on the other hand, a red LED faults open, the LED which is paired with it

will be forced to conduct reverse voltage during the half cycle in which the open faulted LED would have lit.

Those skilled in the art should appreciate that the circuit of Figure 4 exhibits non-linear characteristics and that the most important factor in powering the LEDs is the average current which flows through the array of LEDs. If the voltage drop across the LED array is small relative to the peak line voltage, the current through the array is substantially related to the RMS short circuit current I_{SC} through the inductor L which is expressed below according to the approximation:

$$I_{SC} \approx \frac{V}{Z_L} \qquad (1)$$

where V is the RMS line voltage and Z_L is the impedance of the inductor L. Since it is the average current rather than the RMS current which is of importance to the LEDs, the average short circuit current $I_{SC(AVG)}$ through the inductor L over one complete AC cycle is expressed according to approximation:

$$I_{SC(AVG)} \approx \left(\frac{2\sqrt{2}}{\pi}\right) I_{SC} \qquad (2)$$

It will also be appreciated that the impedance Z_L of the inductor L is a complex number related to its inductance L by:

$$Z_L = |j2\pi FL| \qquad (3)$$

where F is the AC line frequency and j is the square root of (-1). By combining the above approximations (1) and (2) and equation (3), the average short circuit current through the inductor L can be expressed according to:

$$I_{SC(AVG)} \approx \left(\frac{2\sqrt{2}}{\pi}\right)\left(\frac{V}{|j2\pi FL|}\right) \approx \frac{V\sqrt{2}}{\pi^2 FL} \qquad (4)$$

Since each LED is ON for a half cycle and OFF for a half cycle, the average current through current $I_{LED(AVG)}$ through the array during each half cycle will be substantially equal to one half the average short circuit current $I_{SC(AVG)}$ through the inductor L so long as the voltage drop across the LED array is relatively small compared to the peak AC line voltage. For example, utilizing the relationship (4) above with an AC source of 120 V RMS at 60 Hz, an appropriate average current of approximately 24 ma through an array of approximately twenty LEDs every half cycle can be controlled by an inductor L having an inductance of 6 Henries.

The inductor L will maintain an appropriate average current through the array so long as the voltage drop across the array is relatively small as compared to the peak AC line voltage.

The efficiency, power factor, and control of current in the circuit of Figure 4 can be further enhanced by the addition of a capacitor C as shown in Figure 5. The circuit 30a of Figure 5 is substantially the same as that in Figure 4, but with the addition of capacitor C which is coupled in parallel to the LED array 31 across the terminals 33 and 35. In this circuit, the inductance of the inductor L is preferably chosen according to the relationship (4) given above. The L-C circuit shown in Figure 5 is not a filter circuit but is an impedance converter which effectively converts the AC voltage source into a high impedance AC current source when the L-C circuit is tuned to the frequency of the AC source according to approximation:

$$F \approx \frac{1}{2\pi\sqrt{LC}} \tag{5}$$

Thus, the value of the capacitor C is preferably chosen according to the approximation:

$$C \approx \frac{1}{(2\pi F)^2 L} \tag{6}$$

with a frequency of 60 Hz, and an inductor of approximately 6 Henries, the desired capacitance would be approximately 1μF. This arrangement effectively increases the current generator impedance Z_g of the circuit by a factor of Q such that $|Z_g| \approx QX_L$, with X_L being the reactance of the inductor L. It also increases the open circuit voltage V_{DC} by a factor of Q so that $V_{DC} \approx QV$. The AC voltage source therefore appears to the LED array as a current source even when the voltage drop across the array is comparable to the peak AC line voltage. Because of the high current generator impedance, the same tuned circuit can tolerate a wide range in the number and types of LED pairs without materially affecting the LED current. Thus, a standard tuned circuit can be used with many different types of LED arrays. Moreover, in principle, the tuned circuit can generate a voltage across the LED array which may be greater than the AC line voltage. Therefore, a very large number of LEDs can be used in the array. Indeed, in a preferred embodiment of the invention, forty or more pairs of LEDs are utilized. It should be noted that the inductor L, when used in the AC powered circuits described above, provides high impedance without energy wasting resistance.

Referring now to Figure 6, those skilled in the art will appreciate that the LED array 31, the inductor L and the capacitor C can be mounted in a housing 40 having the same size and shape as a conventional incandescent bulb with a conventional base connector 42. In this manner, the array is easily retro-fitted to existing traffic signal displays which utilize this type of fixture.

The invention may be easily adapted to replace incandescent lighting in virtually any kind of traffic signal display unit. Figure 7 shows a popular existing traffic signal display 50 having a weather tight enclosure or casing 52 which contains an incandescent bulb 54 and a parabolic reflector 56. The inside of the enclosure 52 is accessible via a hinged door 58 which carries a colored lens/filter 60 (e.g. red, yellow, or green) fitted to an opening in the door with a grommet 62. The bulb 54 is held in a socket 64 which is electrically coupled to a voltage source (not shown) via a quick connect block 66. The bulb 54, reflector 56, socket 64 and attached wires are also hinged to the enclosure 52. Thus the interior elements of the display 50 are all easily accessible and replaceable.

According to a preferred embodiment of the invention, and as shown in Figures 8 and 9, an LED array 31 is mounted on one side of a circuit board 70 which is provided with circuit traces and elements 72 on its other side. The circuit elements and traces may include the inductor L, the capacitor C, and the connections of the array 31 as described with reference to Figures 4 and 5 above. The circuit board 70 is coupled to a clear plastic disk 74 by a number of spacers 76 so that the LEDs 32 in the array 31 face the disk 74 as seen best in Figure 9. Preferably, both the disk 74 and the circuit board 70 are circular. The disk 72 is fitted with a grommet 62 which is substantially the same as the grommet 62 used to hold the filter/lens 60 in the prior art display 50 described above. The prior art display 50 of Figure 7 is modified by removing the lens/filter 60 with its grommet 62 and by removing the bulb 54, reflector 56, and socket 64. The disk 74 with its grommet 62 is fitted into the opening in the hinged door 53 and the circuit 72 is electrically coupled to the quick connect block 66. It has been found that the portion of the circuit board 70 which faces the disk 74 should be painted black before mounting the LEDs 32. This prevents unwanted reflection off the circuit board during bright daylight hours. It will be appreciated that the circuit 72 need not be mounted on the circuit board 70. All or part of the circuit 72 could be mounted off the board 70 inside the enclosure 52. As a practical matter, it may be advantageous to mount all of the circuit except for the inductor L on the circuit board 70 and mount the inductor L inside the enclosure 52

Figure 10 shows a circuit 30b utilizing multiple LED arrays according to the invention. LED arrays 31a, 31b, 31c, each of which are substantially the same as the LED array 31 shown in Figure 5, are coupled by their first terminals 33a-33c to the AC voltage source 34 through a common inductor L and are coupled by their second terminals 35a-35c through individual respective switches 36a-36c to the AC voltage source. Capacitors C_a, C_b, C_c are respectively coupled in parallel to each array 31a, 31b, 31c across their respective terminals. The circuit shown in Figure 10 assumes that each array is operated in mutual exclusivity so that the L-C circuit as described above operates in the same manner in this circuit when each array is turned

on. This type of circuit is well suited for a multiple display traffic signal. For example, if the LEDs in array 31a are all red light emitting, the LEDs in array 31b are all yellow light emitting, and the LEDs in array 31c are all green light emitting, the circuit is well suited for use in a red, yellow, and green traffic light where only one LED array is turned on at any given time. Using the circuit of Figure 10, a single inductor L can be shared by all of the LED arrays, thereby reducing the cost of the traffic signal display unit.

Figure 11 illustrates an improvement to the circuit of Figure 4 through the addition of an R-C network which increases the power factor. The circuit 130 of Figure 11 is similar to the circuit 30 described above with similar reference numerals (increased by 100 referring to similar parts. The series R-C network across nodes 137, 139 provides two benefits. The value of C can be chosen so that the power factor is greater than 0.9. In particular, C can be chosen to have a reactance similar to the reactance of the remainder of the circuit. The value of R, chosen in conjunction with C, can be chosen so that the R-C network protects the contacts of the switch 136 against arcing.

Figure 12 illustrates an LED module 232 containing four LED pairs 232-1, 232-2, 232-3, 232-4 protected by a pair of Zener diodes Z_a, Z_b. The Zener voltage (V_Z) of each diodes Z_a, Z_b is nominally the same the other. The sum of the Zener voltage (V_Z) of either Zener and the forward threshold of either Zener (V_d) is chosen to be just greater than the peak voltage across the LED pairs. Four LED pairs are shown for example. In practice, m number of LED pairs may be used.

During normal operation, the peak voltage drop (mV_f) across the group of m pairs of LEDs is less than V_Z+V_d and the protective Zener pair Z_A, Z_B do not conduct and are not stressed. If an LED shorts, the protection Zeners are not called into play and the operation is as previously described, except for the loss of light from the pair which includes the shorted LED.

If an LED fails open (e.g. 232-1a) light is lost from all the "a" LEDs in the group of m LED pairs and all of the "b" LEDs in the group still light. The function of the protective Zeners is to limit the voltage drop across the group in the "a" direction to slightly more than the normal mV_f. This excess voltage is readily limited to about 2 volts. The limiting of the difference of voltage drops in opposite directions reduces the DC bias stress on the inductor so that continued operation in this failed mode is practical.

The module 232 is preferably utilized with additional identical modules coupled to each other in series and to an inductor or L-C power supply described above. According to another aspect of the invention, a series circuit is added in series between the LED modules and the

power supply to improve the balance of current flowing in the "a" and "b" directions whether under normal or fault conditions. Figures 13-15 illustrate examples of this type of series circuit.

Figure 13 illustrates a series circuit 241 consisting of a negative temperature coefficient resistor R_{ntc}. The proper choice of the value and temperature coefficient of this resistor can reduce the temperature effect on light output from more than 3 to 1 to less than 1.5 to 1. The value of the resistor may be chosen empirically or with the aid of a graphing function.

Figure 14 shows a series circuit 341 which consists of an incandescent lamp "B". The lamp preferably has a current rating which is at least four times the current which will flow through it. Incandescent lamps increase their effective resistance rapidly as the operating current increases from zero to normal operating conditions. Resistance typically increases by a factor of 2.8 to 1 from 25% to 100% operating current. The benefit of this circuit, at the loss of some efficiency, is improved current regulation with line voltage variations and improved current balance in the "a" and "b" directions under both normal and fault conditions.

Figure 15 shows a series circuit which consists of two incandescent lamps B_a, B_b and two steering diodes D_a, D_b. In this circuit bulb B_a only responds to the current in the "a" LED direction and the B_b lamp only responds to the current in the "b" LED direction. In addition to the benefits of the circuit of Figure 14, this configuration improves the balance of current in the "a" and "b" directions. In order that the life expectancy of the incandescent lamps not materially affect the overall reliability of the overall circuit, the lamps should be operated well below their normal operational conditions.

Figure 16 illustrates an active electronic means for providing the functions of current regulation, current balancing, and temperature compensation at the same time. The basic principle of operation is to sense the current through the LED array 232 and shunt excess current around the array. Shown are two separate shunt regulators, one that senses the current when the "a" LEDs are conducting and one that senses the current when the "b" LEDs are conducting.

The "a" shunt regulator includes resistor R_{SIa}, Zener diode Z_a, transistor Q_a, current drawing resistor R_a, and switching diodes D_{a1}, D_{a2}. The "b" shunt regulator includes resistor R_{SIb}, Zener diode Z_b, transistor Q_b, current drawing resistor R_b, and switching diodes D_{b1}, D_{b2}.

The values of the resistor R_{SIa} is chosen so that when the current in the "a" LEDs exceeds the appropriate value, the voltage across R_{SIa} exceeds the sum of the Zener voltage of Z_a and the base emitter threshold voltage of Q_a, which causes Q_a to turn on thereby by-passing some of the input current around the array through the current drawing resistor R_a. The value of the resistor R_{SIb} is chosen in the same way with respect to the "b" LEDs. The switching diodes D_{a1}, D_{a2} remove the "a" regulator from the circuit when the "b" regulator is functioning and the switching diodes D_{b1}, D_{b2} remove the "b" regulator from the circuit when the "a" regulator is functioning. By incorporating an appropriate temperature sensitive resistance (negative TC) as part of R_{SIa} or R_{SIb}, temperature compensation will be accomplished. Illustratively, if R_{SIa} increases in value as ambient temperature goes down, by-pass current will start at a lower LED current as temperature decreases.

Figure 17 illustrates an improvement to the circuit of Figure 5 through the addition of an R-C network R and C_1 which is parallel to the L-C circuit and which increases the power factor. The circuit 130a of Figure 17 is similar to the circuit 30a (Figure 5) described above with similar reference numerals (increased by 100) referring to similar parts. The series R-C network across nodes 137, 139 provides two benefits. The value of C_1 can be chosen so that the power factor is greater than 0.9. The value of R, chosen in conjunction with C_1, can be chosen so that the R-C network protects the contacts of the switch 136 against arcing.

Figure 18 illustrates a circuit similar to the circuit 30a (Figure 5) described above with similar reference numerals (increased by 200) referring to similar parts. This circuit 230a differs from the circuit 30a by the inclusion of a negative temperature coefficient resistor R_{NTC} in series between node 237 and the inductor L. The resistor R_{NTC} changes resistance in response to changes in temperature and thereby compensates for the sensitivity of LEDs to temperature.

Figure 19 illustrates a circuit similar to the circuit 30a (Figure 5) described above with similar reference numerals (increased by 300) referring to similar parts. This circuit 330a differs from the circuit 30a by the inclusion of a step-down autotransformer L_P across the nodes 333, 335. The inductance of transformer L_P is preferably greater than or equal to four times the inductance of inductor L and the tap coefficient (k) is preferably less than 1.0. This circuit provides, across nodes 333', 335', a lower voltage and a higher current than provided by the circuit 30a across nodes 33, 35. In particular, the circuit increases the short circuit current by a factor 1/k and decreases the open circuit voltage by the factor k. This circuit is useful for powering an LED array which requires more current and less voltage, e.g. a parallel array.

Figure 20 illustrates a circuit 331 which can replace the LED array 31, 131, 231 described above. The circuit 331 includes a series LED array 332, a full wave rectifier D_1-D_4 and a filtering capacitor C_F. The advantages of using this circuit in conjunction with the L or L-C power supply of the invention are several. The peak to average current ratio approaches 1.0 and light modulation (flicker) is significantly reduced. More complex series-parallel arrays can be used such as those described below with reference to Figures 23, 26, and 27. DC current issues do not exist for the inductor. Since current is only flowing in one direction it is not necessary to balance the current flow in opposite direction.

Figure 21 illustrates a circuit similar to the circuit illustrated in Figure 20 but with improved failure performance. The LED array 432 includes "n" groups of "m" series connected LEDs. Each group of "m" LEDs has a parallel connected Zener diode Z_a which conducts if one of the LEDs in the group should fail open.

Figure 22 illustrates a circuit similar to the circuit illustrated in Figure 21 but with a shunt regulator similar to those described above with reference to Figure 16. The shunt regulator includes resistors R_1, R_{SA}, transistor Q_1, and Zener diode Z_b. The shunt regulator provides current regulation and temperature compensation as described above.

Those skilled in the art will appreciate that in an array of series connected LEDs the current is the same in all the LEDs. In an array of parallel connected LEDs, the current in each LED differs. Generally, the series connected array is preferable but for the need to protect the array from an open failed LED. Figure 23 illustrates a complex array of "m" series arrays coupled in parallel. As shown in Figure 23, each series array 632-1 through 632-n is provided with a sharing impedance 641-1 through 641-n. The sharing impedance is preferably comparable to the total dynamic impedance of the array alone. Figures 24 and 25 illustrate that the sharing impedance 641 may be either a resistor 641' or an incandescent lamp 641". The non-linear characteristics of the lamp produces better balance and more efficiency than the resistor.

Figure 26 illustrates a circuit 731 similar to the circuit 631 described above, but with an electronic current balancing circuit for balancing two series LED arrays 732-1 and 732-2 which are coupled parallel to each other. The current balancing circuit includes seven resistors R_1-R_6, R_C and two transistors Q_1, Q_2 which form a differential current steering circuit. In normal operation, the current through resistors R_1, R_C, and R_2 is equal. If an LED in the array 732-1 fails open, the voltage across resistor R_1 will drop lower than the voltage across the resistor R_2. A higher dynamic impedance is created at the node of R_5 and the collector of Q_2 than the sum of R_1 and R_5.. This causes the differential transistors Q_1, Q_2 to steer more of the current

through the resistor R_C to the array 732-1 and less to the array 732-2. The circuit 731 provides excellent balance and efficiency.

Figure 27 illustrates a circuit 731a which is substantially the same as circuit 731 with the addition of a shunt regulator such as described above with reference to Figures 16 and 22. The shunt regulator includes resistors R_{SA}, R_7, transistor Q_3 and Zener diode Z. In addition, the circuit 731a optionally includes a negative temperature compensation resistor R_{NTC}.

Figure 28 illustrates a circuit 830 which is similar to the circuit 30a of Figure 5 but with the location of the inductor L and capacitor C interchanged. Circuit 830 is not as preferred as embodiment as the circuit 30a has a better power factor and lower harmonic distortion. However, one advantage of circuit 830 is that the exciting voltage of the inductor is limited to the LED array voltage which may allow the inductor to be smaller and cheaper. Another advantage of interchanging the locations of the inductor and capacitor is illustrated in Figure 29.

Figure 29 illustrates a circuit 830a which is substantially the same as the circuit 830 but where the inductor L is provided with a tap to provide the function of a step down autotransformer as described above with reference to Figure 19 without the addition of an additional component.

Figure 30 illustrates a pair of LED arrays 932-1, 932-2, each having an associated series circuit 941-1, 941-2, and a double pole double throw switch 951 controlled by unit 953. The switch 951 changes the circuit arrangement so that the LED arrays may be arranged in series or in parallel (shown). The average current through individual LEDs when the arrays are in series is approximately twice current through individual LEDs when the arrays are in parallel. Thus, the total light output of the two arrays is either doubled or halved by toggling the switch 951. According to the invention, the switching unit 953 may be used to compensate for temperature or may be used to dim the LEDs at night. Figure 31 shows a controller unit 953' which includes a relay 955 and a photocell 957 designed to dim the LEDs at night. It will be appreciated that the photocell 957 is provided with a filter (not shown) which filters out the wavelength of the LEDs.

Figure 32 shows a circuit 1030 which is similar to the circuit shown in Figure 21 having an inductor L, a capacitor C, a series LED array 1032 with a full wave rectifier D_1-D_4, and a filter capacitor C_F. The circuit 1030 also includes an LED array current sensor and controller 1059, a zero crossing detector 1061, and an opto relay 1063. Those skilled in the art will appreciate that at the time the voltage across the capacitor C is crossing zero, the current

stored in the inductor L is near its peak and is about to be passed into the load. The circuit of Figure 32 causes the voltage across the capacitor to be momentarily held at zero after the zero crossing instant. This causes the inductor to be charged with a higher current than it would otherwise thereby delivering more current (power) to the load. The LED current sensor and controller 1059 measures the difference between the desired average current and the actual average current. A voltage proportional to the difference is stored on a capacitor (not shown). At the time that the zero crossing is indicated by the detector 1061, the controller 1059 generates a pulse having a length proportional to the aforementioned stored voltage. (Below some threshold, no pulse is generated.) The pulse is used to activate the opto relay 1063 which shorts the capacitor C for the duration of the pulse. Since the relay shorts the capacitor when the energy in it is zero, this circuit is in principle lossless.

Figure 33 illustrates a system according to the invention having a separate LED circuit 1130 and traffic light controller circuit 1170. The LED circuit 1130 may be any of the circuits previously described. The controller circuit 1170 includes a triac 1172 which is controlled by a controller 1174 in response to inputs 1176, 1178, 1180. The inputs 1176, 1178, 1180 may include a temperature sensor, a voltage sensor, a photocell, etc. The triac and controller, therefore, control the brightness of the LED array as well as whether it is on or off. Those skilled in the art will appreciate that a similar triac and controller could be located in the LED assembly 1130, rather than at the traffic controller location, to provide appropriate dimming of the LED array while the traffic controller only controls whether the array is on or off.

There have been described and illustrated herein several embodiments of an AC powered LED array and circuits associated with it. While particular embodiments of the invention have been described, it is not intended that the invention be limited thereto, as it is intended that the invention be as broad in scope as the art will allow and that the specification be read likewise. Thus, while particular configurations have been disclosed in reference to a housing for the LED array and associated circuits, it will be appreciated that other configurations could be used as well. Furthermore, while the circuit of the invention has been described with reference to traffic signal displays, it will be appreciated that the circuit is useful in any AC powered illumination apparatus, including, but not limited to illuminated safety displays such as fire alarm indicators, exit signs, airport and shipping displays, etc. It will therefore be appreciated by those skilled in the art that yet other modifications could be made to the provided invention without deviating from its spirit and scope as so claimed.

Claims:

1. An LED array circuit powered by a substantially sinusoidal AC voltage source of known frequency, comprising:

a) a first set of LEDs arranged as a first plurality of LED pairs, each LED pair comprising two oppositely polarized LEDs coupled to each other in parallel, and each LED pair being series connected to another LED pair, said first set of LEDs having first and second terminal nodes, coupled to and across the substantially sinusoidal AC voltage source;

b) an inductor arranged in series with and coupling one of said first and second terminal nodes to the substantially sinusoidal AC voltage source, said inductor having a Q value and reactance chosen for improved power efficiency; and

c) a first capacitor coupled in parallel to said first set of LEDs at said first and second terminal nodes, wherein said inductor and said first capacitor form an impedance converter circuit which is tuned to the known frequency of the substantially sinusoidal AC voltage source thereby effectively converting the AC voltage source into substantially an AC current source, said substantially AC current source with said first set of LEDs providing said circuit with improved power efficiency.

2. A circuit according to claim 1, wherein:

said inductor has a Q greater than five.

3. A circuit according to claim 1, wherein:

said first set of LEDs comprises at least forty LEDs.

4. A circuit according to claim 1, wherein:

the values of said inductor and said first capacitor are chosen according to the approximate relationship $F \approx \frac{1}{2\pi\sqrt{LC}}$,

where F is the frequency of the substantially sinusoidal AC voltage source, L is the value of said inductor, and C is the value of said first capacitor.

5. A circuit according to claim 1, further comprising:

d) a second plurality of LED pairs, each second plurality of LED pairs comprising two oppositely polarized LEDs, said second plurality of LED pairs being coupled to each other in series to form a second set of series connected LEDs having two terminal nodes coupled to and across the substantially sinusoidal AC voltage source, one of said two terminal nodes of the second plurality of series connected LEDs being coupled to the substantially sinusoidal AC voltage source by said inductor.

6. A circuit according to claim 5, further comprising:

e) a first switch means for coupling said first set of series connected LEDs to the substantially sinusoidal AC voltage source; and

f) a second switch means for coupling said second set of series connected LEDs to the substantially sinusoidal AC voltage source.

7. A circuit according to claim 1, further comprising:

d) a second plurality of LED pairs, each pair of said second plurality of LED pairs comprising two oppositely polarized LEDs, said second plurality of LED pairs being coupled to each other in series to form a second set of series connected LEDs having two terminal nodes coupled to and across said substantially sinusoidal AC voltage source, with one of said terminal nodes being coupled by said inductor to the substantially sinusoidal AC voltage source; and

e) a second capacitor coupled in parallel with said second set of series connected LEDs.

8. A circuit according to claim 7, further comprising:

f) a first switch means for coupling said first set of series connected LEDs to the substantially sinusoidal AC voltage source; and

g) a second switch means for coupling said second set of series connected LEDs to the substantially sinusoidal AC voltage source.

9. A circuit according to claim 1, wherein:

said first set of series connected LEDs are mounted on one side of a substantially circular circuit board, and

said substantially circular circuit board is attached to a substantially circular clear plastic disk with spacers such that said first plurality of series connected LEDs face said clear plastic disk.

10. An LED array circuit powered by a substantially sinusoidal AC voltage source of known frequency, comprising:

a) a plurality of series connected LEDs having first and second terminal nodes, coupled to and across the substantially sinusoidal AC voltage source, said plurality of series connected LEDs comprising a plurality of LED pairs, each LED pair comprising two oppositely polarized LEDs coupled to each other in parallel, and each LED pair being series connected to another LED pair;

b) an inductor arranged in series with and coupling one of said first and second terminal nodes to the substantially sinusoidal AC voltage source; and

c) a first capacitor coupled in parallel to said plurality of series connected LEDs at said first and second terminal nodes, wherein said inductor and said first capacitor form an impedance converter circuit which is tuned to the known frequency of the substantially sinusoidal AC voltage source thereby effectively converting the AC voltage source into substantially an AC current source, wherein

said plurality of series connected LEDs comprising a number of LEDs sufficient to cause a voltage drop across said first set of LEDs to be greater than a peak voltage of the AC voltage source.

11. A circuit according to claim 10, wherein:

said inductor has a Q greater than five.

12. A circuit according to claim 10, wherein:

the values of said inductor and said first capacitor are chosen according to the approximate relationship $F \approx \frac{1}{2\pi\sqrt{LC}}$,

where F is the frequency of the substantially sinusoidal AC voltage source, L is the value of said inductor, and C is the value of said first capacitor.

13. A circuit according to claim 1, wherein:

said Q value is at least five.

14. An LED array circuit powered by a substantially sinusoidal AC voltage source of known frequency, comprising:
a) a first set of LEDs arranged as a first plurality of LED pairs, each LED pair comprising two oppositely polarized LEDs coupled to each other in parallel, and each LED pair being series connected to another LED pair, said first set of LEDs having first and second terminal nodes, coupled to and across the substantially sinusoidal AC voltage source;
b) an inductor arranged in series with and coupling one of said first and second terminal nodes to the substantially sinusoidal AC voltage source; and
c) a first capacitor coupled in parallel to said first set of LEDs at said first and second terminal nodes, wherein said inductor and said first capacitor form an impedance converter circuit which is tuned to the known frequency of the substantially sinusoidal AC voltage source thereby effectively converting the AC voltage source into substantially an AC current source, said inductor having an inductance value chosen to provide a desired current for lighting said first set of LEDs, and said inductor chosen to have a high impedance while providing energy efficiency.

15. A circuit according to claim 14, further comprising:
d) a second plurality of LED pairs, each second plurality of LED pairs comprising two oppositely polarized LEDs, said second plurality of LED pairs being coupled to each other in series to form a second set of series connected LEDs having two terminal nodes coupled to and across the substantially sinusoidal AC voltage source, one of said two terminal nodes of the second plurality of series connected LEDs being coupled to the substantially sinusoidal AC voltage source by said inductor.

16. A circuit according to claim 15, further comprising:
e) a first switch means for coupling said first set of series connected LEDs to the substantially sinusoidal AC voltage source; and
f) a second switch means for coupling said second set of series connected LEDs to the substantially sinusoidal AC voltage source.

17. A circuit according to claim 14, further comprising:
d) a second plurality of LED pairs, each pair of said second plurality of LED pairs comprising two oppositely polarized LEDs, said second plurality of LED pairs being coupled to each other in series to form a second set of series connected LEDs having two terminal nodes coupled to and across said substantially sinusoidal AC voltage source, with one of said terminal nodes being coupled by said inductor to the substantially sinusoidal AC voltage source; and
e) a second capacitor coupled in parallel with said second set of series connected LEDs.

18. A circuit according to claim 17, further comprising:

f) a first switch means for coupling said first set of series connected LEDs to the substantially sinusoidal AC voltage source; and

g) a second switch means for coupling said second set of series connected LEDs to the substantially sinusoidal AC voltage source..

19. A circuit according to claim 14, wherein:

said first set of series connected LEDs are mounted on one side of a substantially circular circuit board, and

said substantially circular circuit board is attached to a substantially circular clear plastic disk with spacers such that said first plurality of series connected LEDs face said clear plastic disk.

20. An LED array circuit powered by a substantially sinusoidal AC voltage source, comprising:

a) a first plurality of series connected LEDs having first and second terminal nodes, coupled to and across the substantially sinusoidal AC voltage source; and

b) a current limiting inductor arranged in series with and coupling one of said first and second terminal nodes to the substantially sinusoidal AC voltage source, said inductor having an inductance value chosen to provide a desired current through said LEDs, and having a Q value and reactance for improved power efficiency.

21. A circuit according to claim 20, further comprising:

c) a second plurality of series connected LEDs having two terminal nodes, one of said terminal nodes of said second plurality of LEDs being coupled to said first terminal node of said first plurality of LEDs, and the other of said terminal nodes of said second plurality of LEDs being coupled to said second of said terminal nodes of said first plurality of LEDs, such that said first plurality of LEDs are polarized in a first direction and said second plurality of LEDs are polarized in second direction opposite to said first direction.

22. A circuit according to claim 20, wherein:

said first plurality of series connected LEDs comprises a first plurality of LED pairs, each LED pair comprising two oppositely polarized LEDs coupled to each other in parallel, and each LED pair being series connected to another LED pair.

23. A circuit according to claim 22, wherein:

said inductor has a Q greater than five.

24. A circuit according to claim 20, wherein:
said inductor has a Q greater than five.

25. A circuit according to claim 22, further comprising:
c) a second plurality of LED pairs, each LED pair comprising two oppositely polarized LEDs, said second plurality of LED pairs being coupled to each other in series to form a second plurality of series connected LEDs having two terminal nodes coupled to and across the substantially sinusoidal AC voltage source, one of said two terminal nodes of the second plurality of series connected LEDs being coupled to the substantially sinusoidal AC voltage source by said inductor.

26. A circuit according to claim 25, further comprising:
d) a first switch means for coupling said first plurality of series connected LEDs to the substantially sinusoidal AC voltage source; and
e) a second switch means for coupling said second plurality of series connected LEDs to the substantially sinusoidal AC voltage source.

27. A circuit according to claim 26, further comprising:
f) a first capacitor coupled in parallel to said first plurality of series connected LEDs at said first and second terminal nodes.

28. A circuit according to claim 20, further comprising:
c) a first capacitor coupled in parallel to said first plurality of series connected LEDs at said first and second terminal nodes.

29. A circuit according to claim 20, wherein:
said first plurality of series connected LEDs are mounted on one side of a substantially circular circuit board, and
said substantially circular circuit board is attached to a substantially circular clear plastic disk with spacers such that said first plurality of series connected LEDs face said clear plastic disk.

30. A circuit according to claim 20, further comprising:
c) an R-C circuit coupled across said substantially sinusoidal AC voltage source.

31. A circuit according to claim 20, further comprising:
c) at least one Zener diode coupled in parallel with at least some of said series connected LEDs.

32. A circuit according to claim 20, further comprising:
c) a negative temperature coefficient resistor coupled in series with said first plurality of series connected LEDs.

33. A circuit according to claim 20, further comprising:
c) an incandescent lamp coupled in series with said first plurality of series connected LEDs.

34. A circuit according to claim 20, further comprising:
c) a current regulation circuit coupled in series with said first plurality of series connected LEDs.

35. A circuit according to claim 34, wherein:
said current regulation circuit comprises a first incandescent lamp, a second incandescent lamp coupled in parallel with said first incandescent lamp, a first diode coupled in series with said first incandescent lamp, and a second diode coupled in series with said second incandescent lamp, said first and second diodes being oppositely oriented.

36. A circuit according to claim 20, further comprising:
c) a current regulation circuit coupled in parallel with said first plurality of series connected LEDs.

37. A circuit according to claim 36, wherein:
said current regulation circuit includes a Zener diode and a transistor.

38. A circuit according to claim 20, further comprising:
c) a first capacitor coupled in parallel to said first plurality of series connected LEDs.

39. A circuit according to claim 38, further comprising:
d) an R-C circuit coupled across said substantially sinusoidal AC voltage source.

40. A circuit according to claim 38, further comprising:
d) a negative temperature coefficient resistor coupled in series with said first plurality of series connected LEDs.

41. A circuit according to claim 38, further comprising:

d) a full wave rectifier and a filter capacitor coupled in parallel with said first plurality of series connected LEDs.

42. A circuit according to claim 41, further comprising:

e) at least one Zener diode coupled in parallel with at least some of said series connected LEDs.

43. A circuit according to claim 38, further comprising:

d) a current regulation circuit coupled in series with said first plurality of series connected LEDs.

44. A circuit according to claim 43, wherein:

said current regulation circuit includes an incandescent lamp.

45. A circuit according to claim 43, wherein:

said current regulation circuit includes a resistor.

46. A circuit according to claim 43, wherein:

said current regulation circuit includes a transistor.

47. A circuit according to claim 38, further comprising:

d) a current regulation circuit coupled in parallel with said first plurality of series connected LEDs.

48. A circuit according to claim 47, wherein:

said current regulation circuit includes a Zener diode and a transistor.

49. A circuit according to claim 20, further comprising:

c) a brightness control circuit coupled to said first plurality of series connected LEDs.

50. A circuit according to claim 49, wherein:

said brightness control circuit includes a second plurality of series connected LEDs and a switch means coupled to said first plurality of series connected LEDs and said second plurality of series connected LEDs,

said switch means selectively coupling said first plurality of series connected LEDs and said second plurality of series connected LEDs in series or in parallel with each other.

51. A circuit according to claim 49, further comprising:

d) sensor means for sensing a first ambient condition, said sensor means coupled to said brightness control circuit such that said brightness control circuit is responsive to said first ambient condition.

52. A circuit according to claim 51, wherein:

said first ambient condition is temperature.

53. A circuit according to claim 51, wherein:

said first ambient condition is daylight.

54. A circuit according to claim 51, wherein:

said first ambient condition is the voltage value of said substantially sinusoidal voltage source.

55. A circuit according to claim 49, wherein:

said brightness control circuit includes a triac coupled in series with said first plurality of series connected LEDs.

56. A circuit according to claim 55, further comprising:

d) sensor means for sensing a first ambient condition, said sensor means coupled to said triac such that said triac is responsive to said first ambient condition.

57. A circuit according to claim 56, wherein:

said first ambient condition is temperature.

58. A circuit according to claim 56, wherein:

said first ambient condition is daylight.

59. A circuit according to claim 56, wherein:

said first ambient condition is the voltage value of said substantially sinusoidal voltage source.

60. A circuit according to claim 38, further comprising:

d) a relay coupled in parallel with said first capacitor for selectively shorting out said capacitor;

e) a zero crossing detector for detecting when the voltage through said capacitor is crossing zero, said zero crossing detector coupled to said relay for shorting out said capacitor when the voltage through said capacitor is crossing zero.

61. A circuit according to claim 60, further comprising:

f) a current sensor and controller coupled to said first plurality of series connected LEDs, coupled to said zero crossing detector, and coupled to said relay, whereby said relay is activated for a period of time in proportion to the difference between the actual average current and a desired average current.

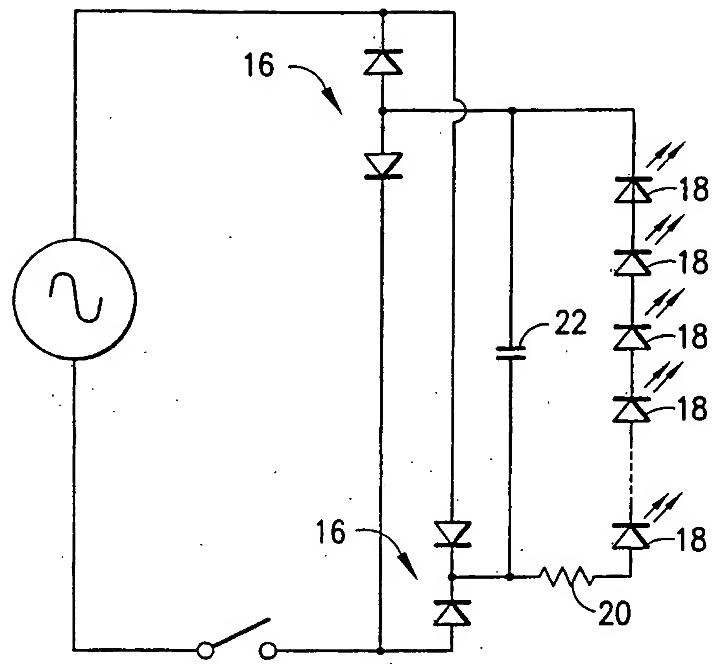


FIG.2
PRIOR ART

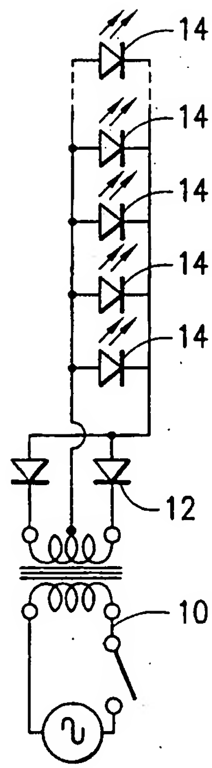


FIG.1
PRIOR ART

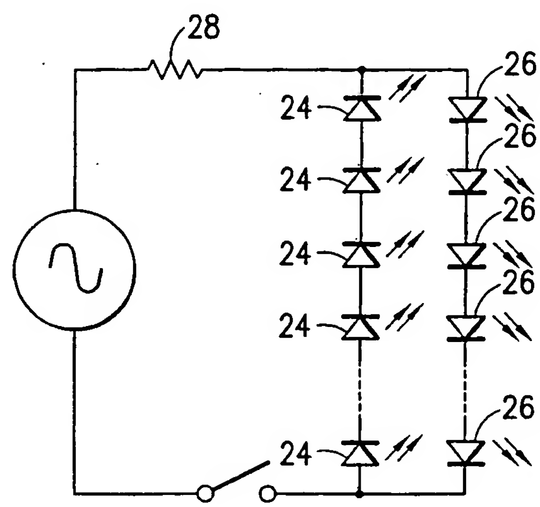


FIG.3
PRIOR ART

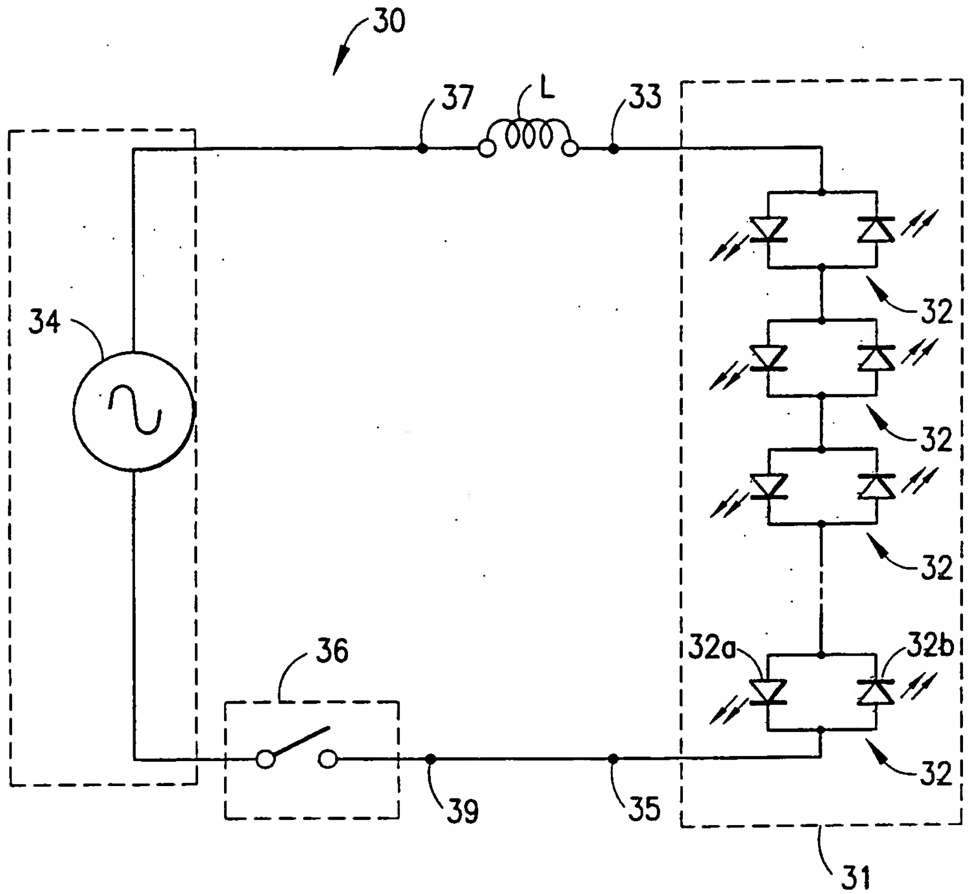


FIG.4

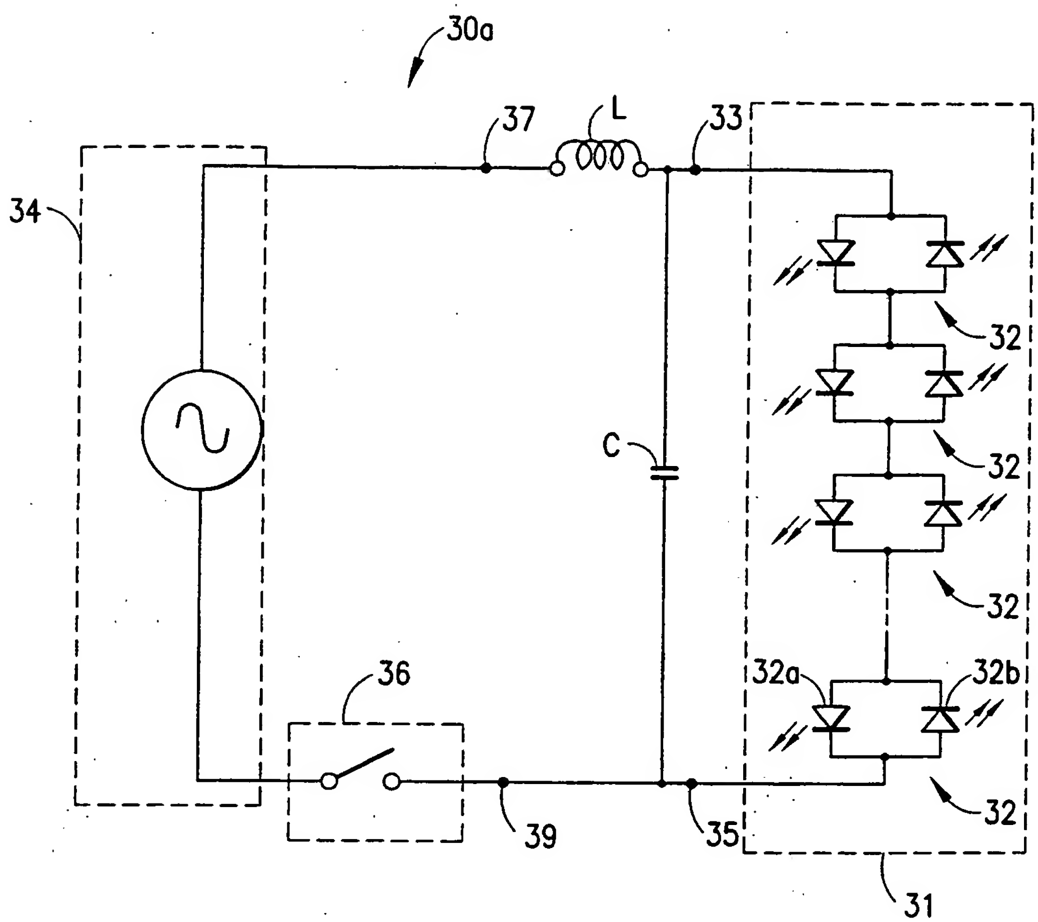


FIG.5

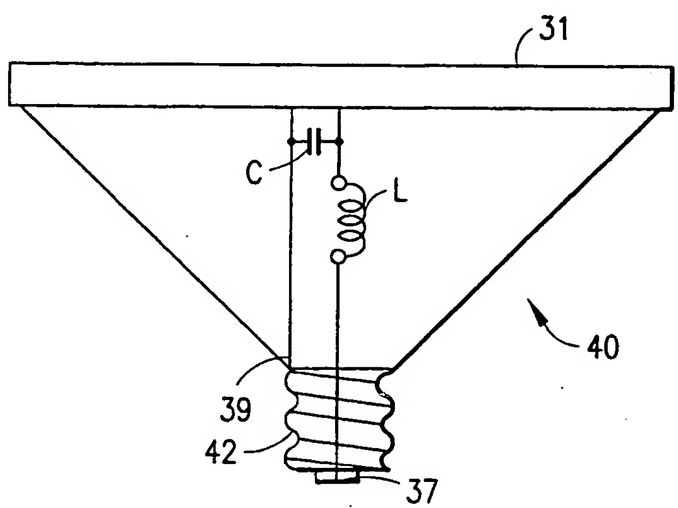


FIG.6

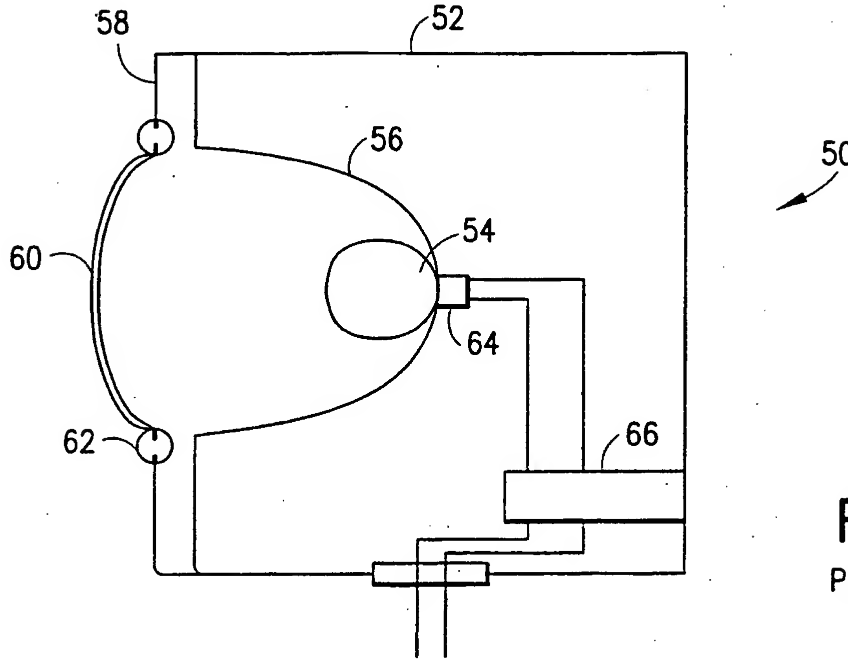


FIG.7
PRIOR ART

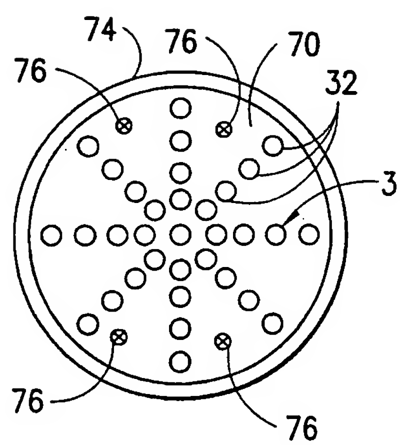


FIG.8

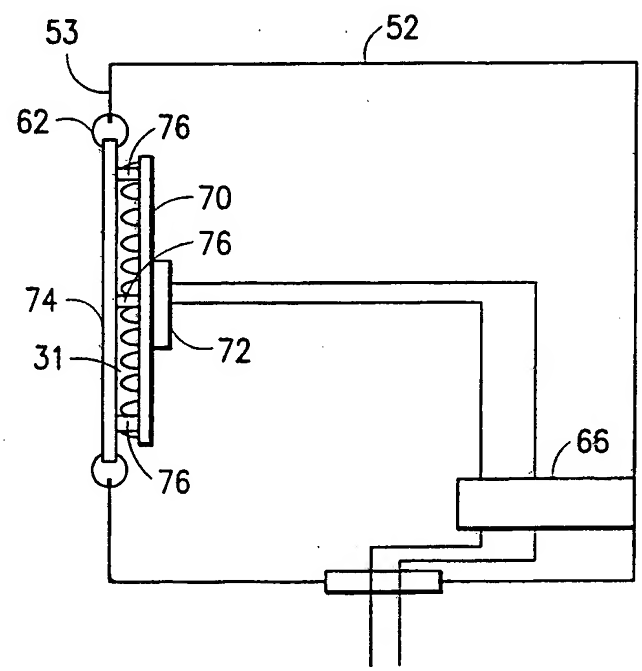


FIG.9

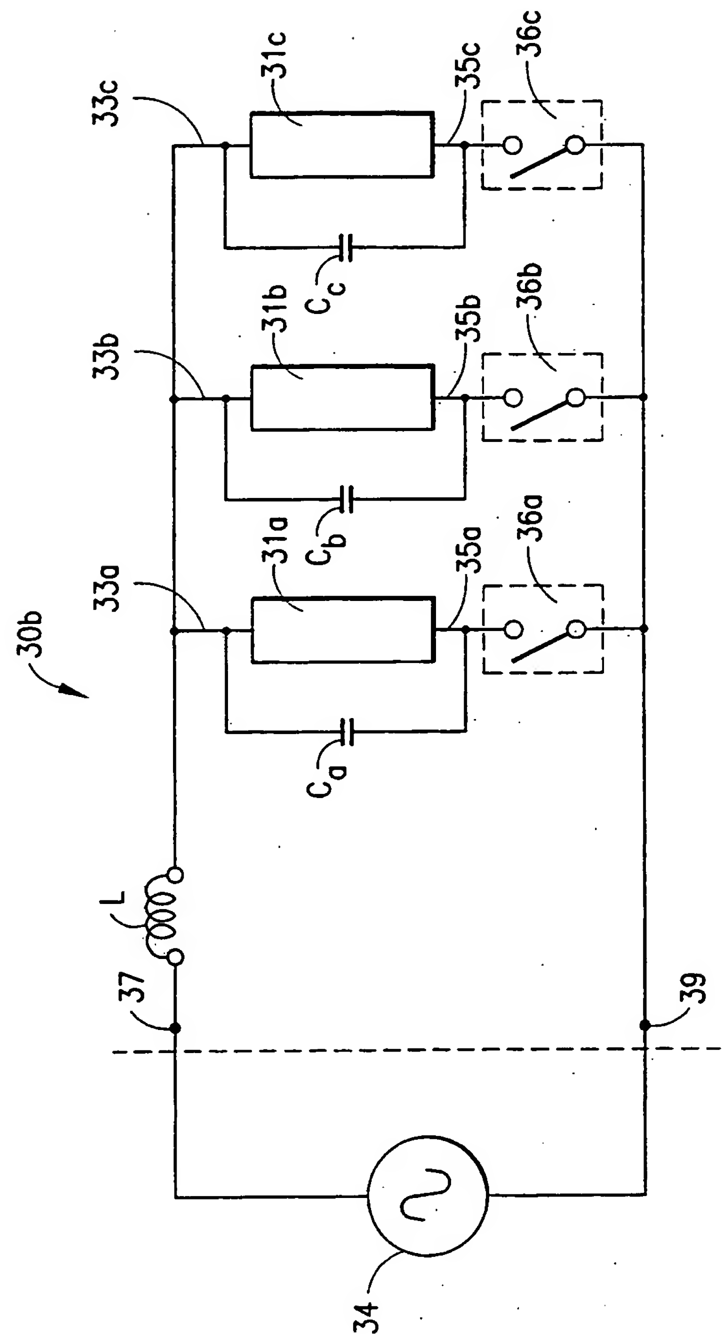

33c
31c
35c
36c
C_c
33b
31b
35b
36b
C_b
33a
31a
35a
36a
C_a
30b
L
37
39
34

FIG.10

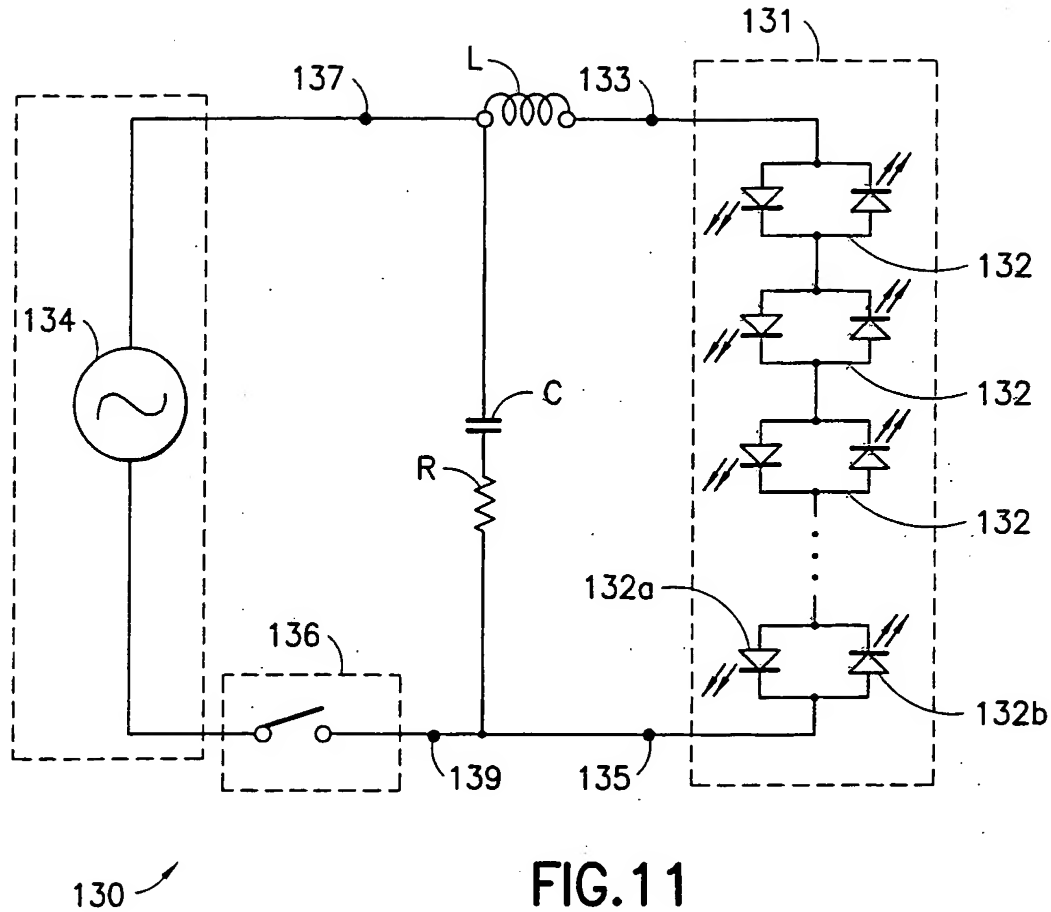

131
137
L
133
132
134
132
C
132
R
132a
136
132b
139
135
130

FIG.11

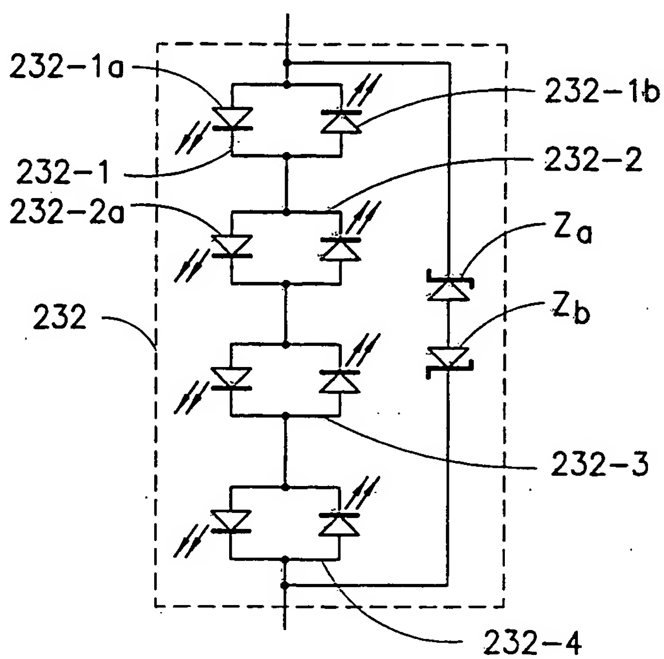

232-1a
232-1b
232-1
232-2
232-2a
Za
232
Zb
232-3
232-4

FIG.12

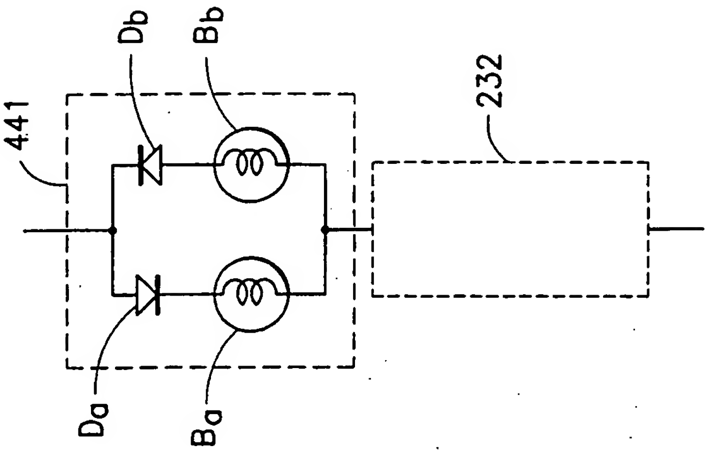


FIG.15

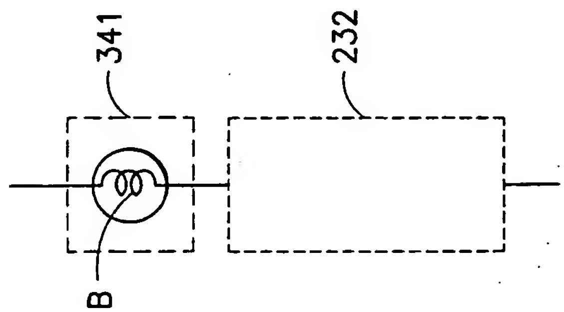


FIG.14

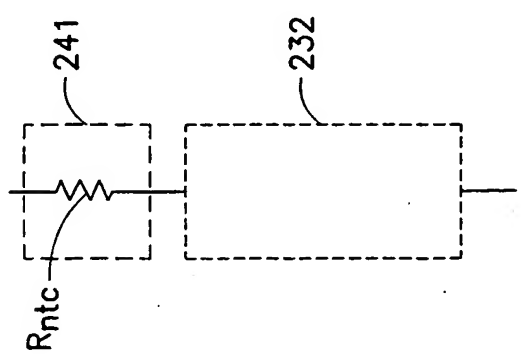


FIG.13

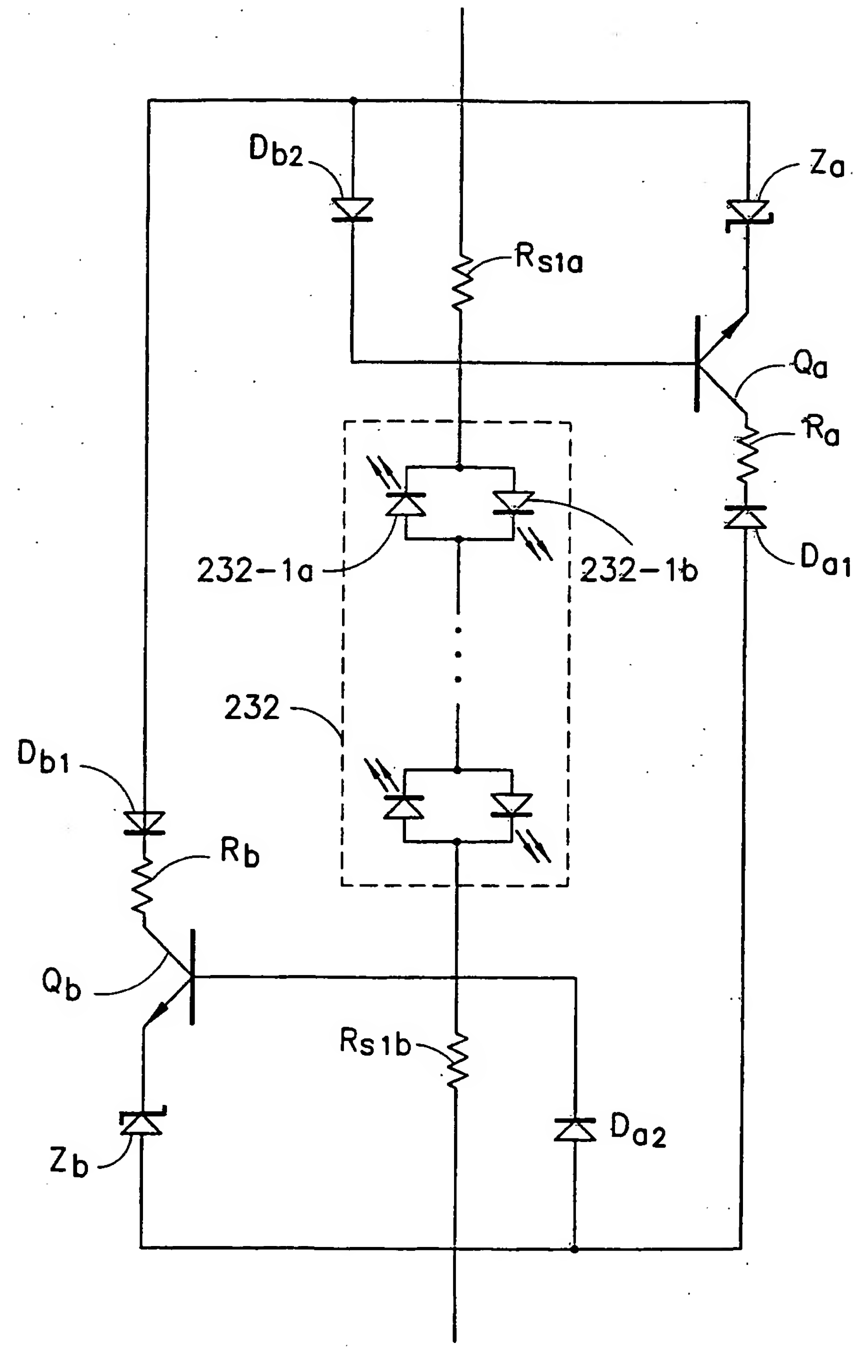


FIG.16

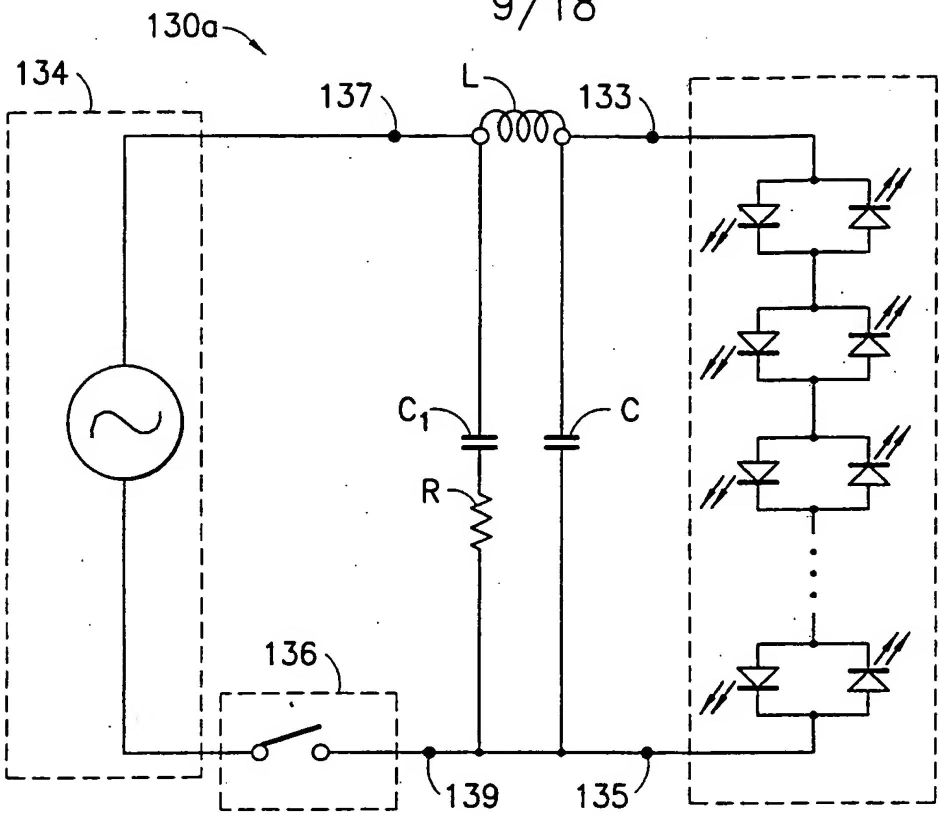

130a
134
137
L
133
131
C1
C
R
136
139
135

FIG.17

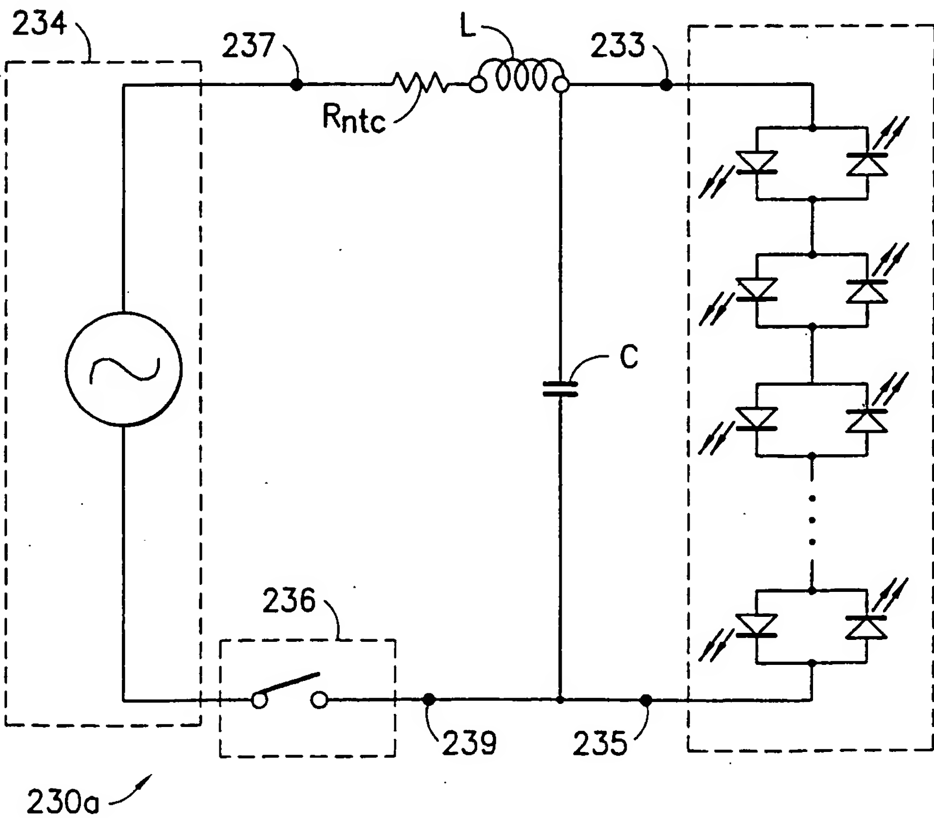

234
237
L
233
Rntc
231
C
236
239
235
230a

FIG.18

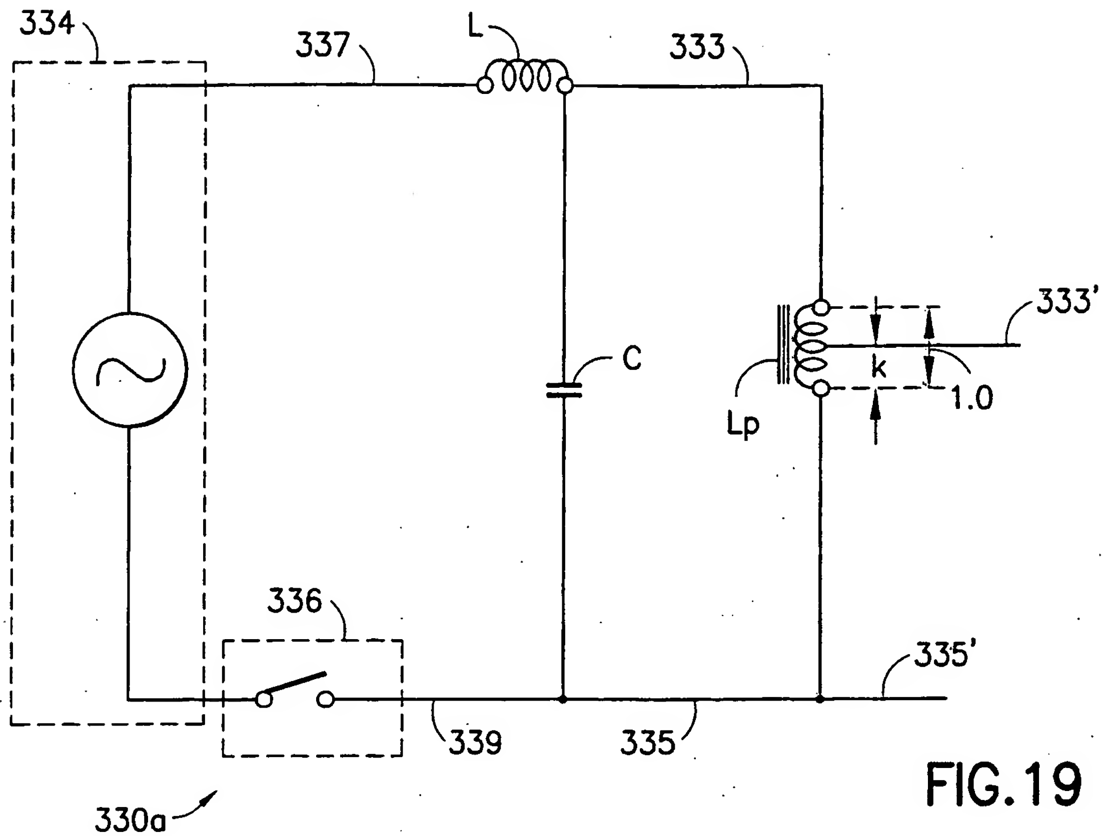

334
337
L
333
C
333'
k
1.0
Lp
336
335'
339
335
330a

FIG.19

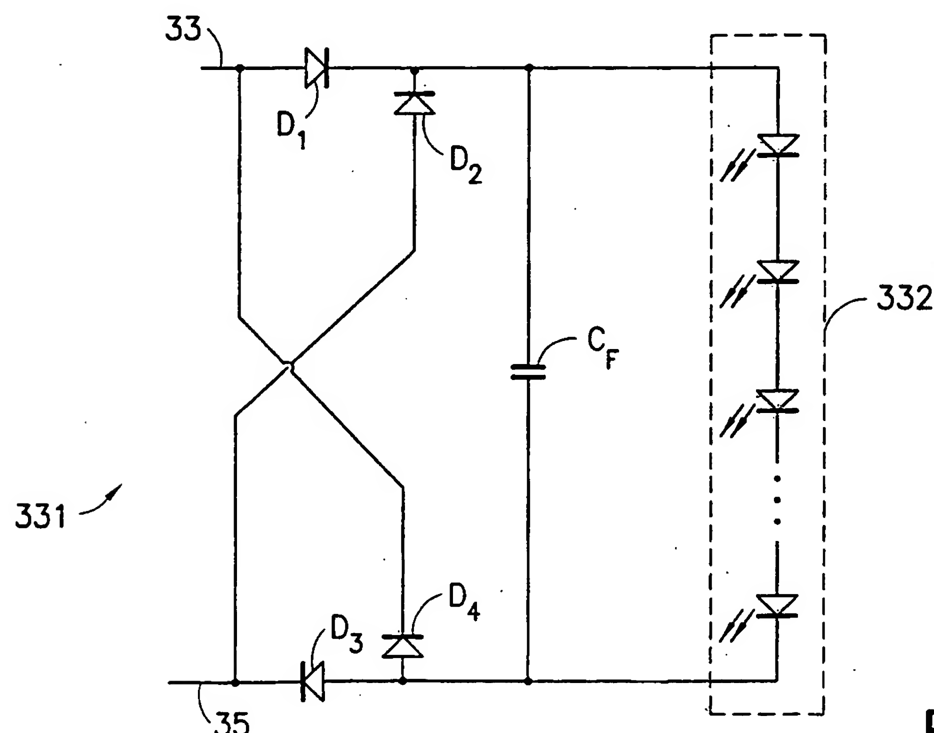

33
D_1
D_2
C_F
332
331
D_3
D_4
35

FIG.20

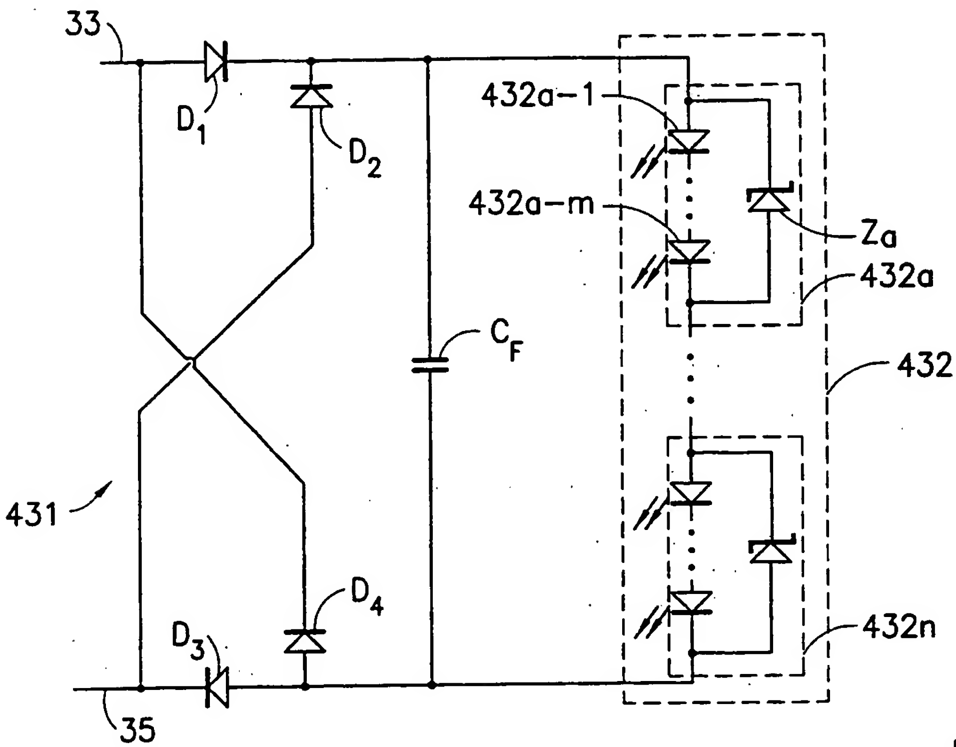

33
D1
D2
432a-1
432a-m
Za
432a
432
CF
431
D4
D3
432n
35

FIG.21

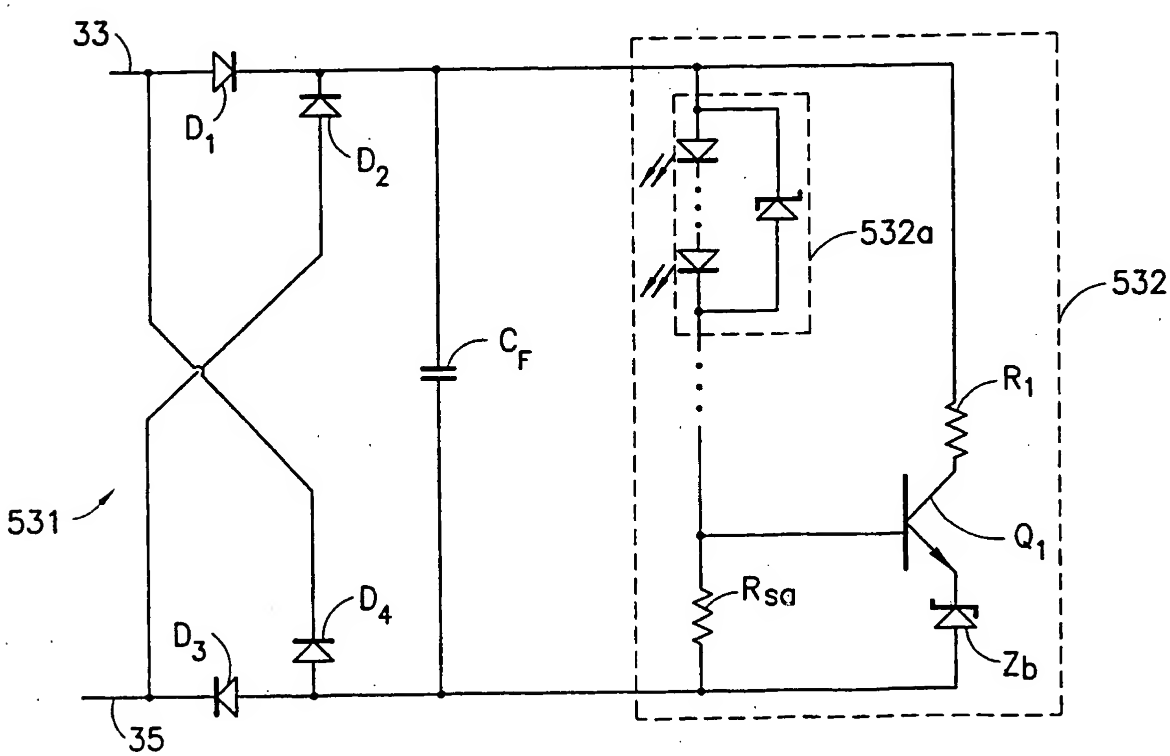

33
D1
D2
532a
532
CF
R1
531
Q1
D4
Rsa
D3
Zb
35

FIG.22

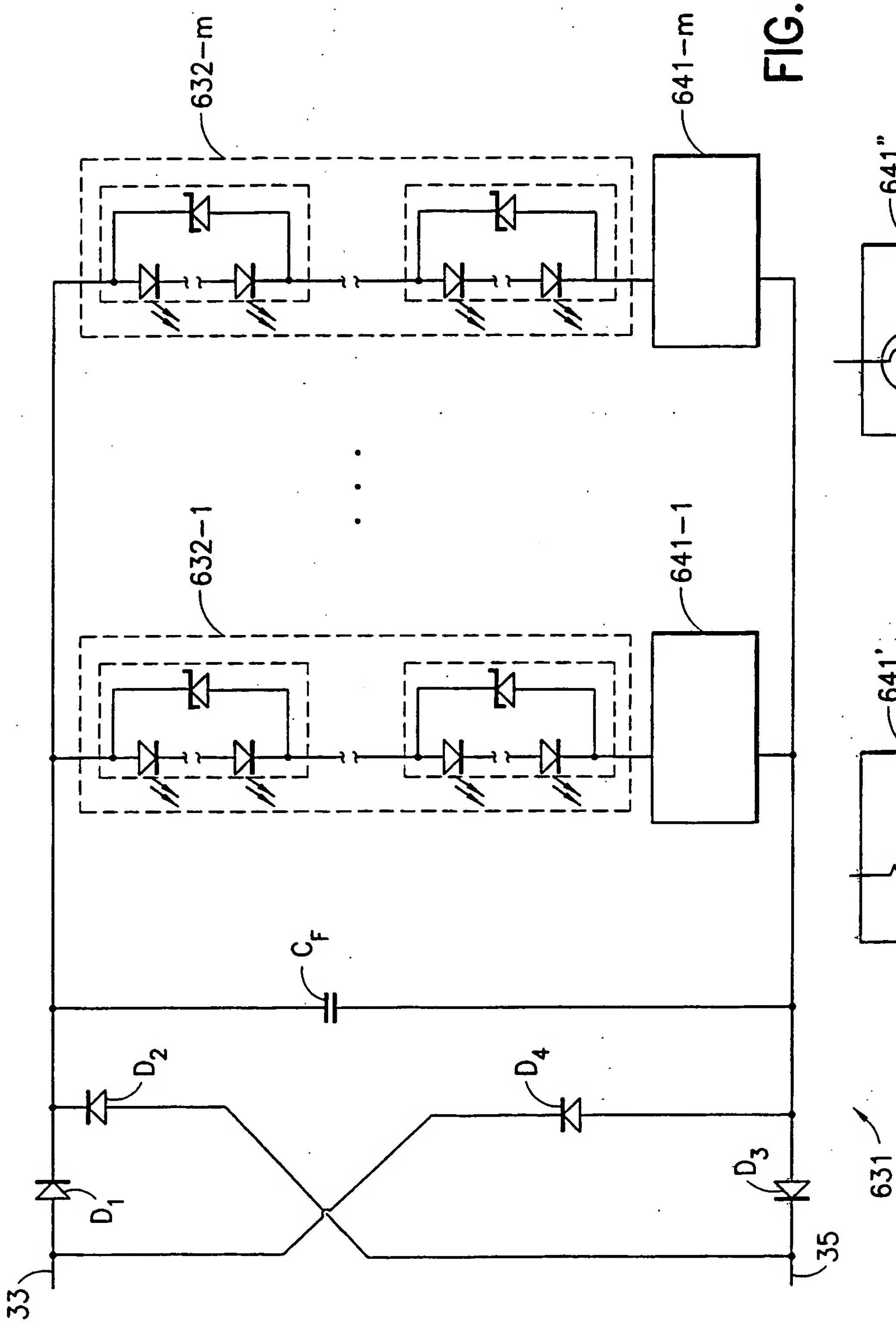


FIG.23

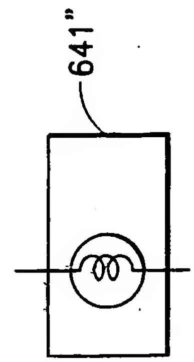


FIG.25

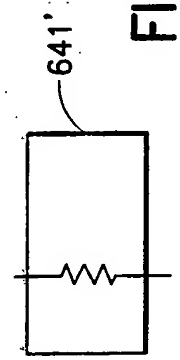
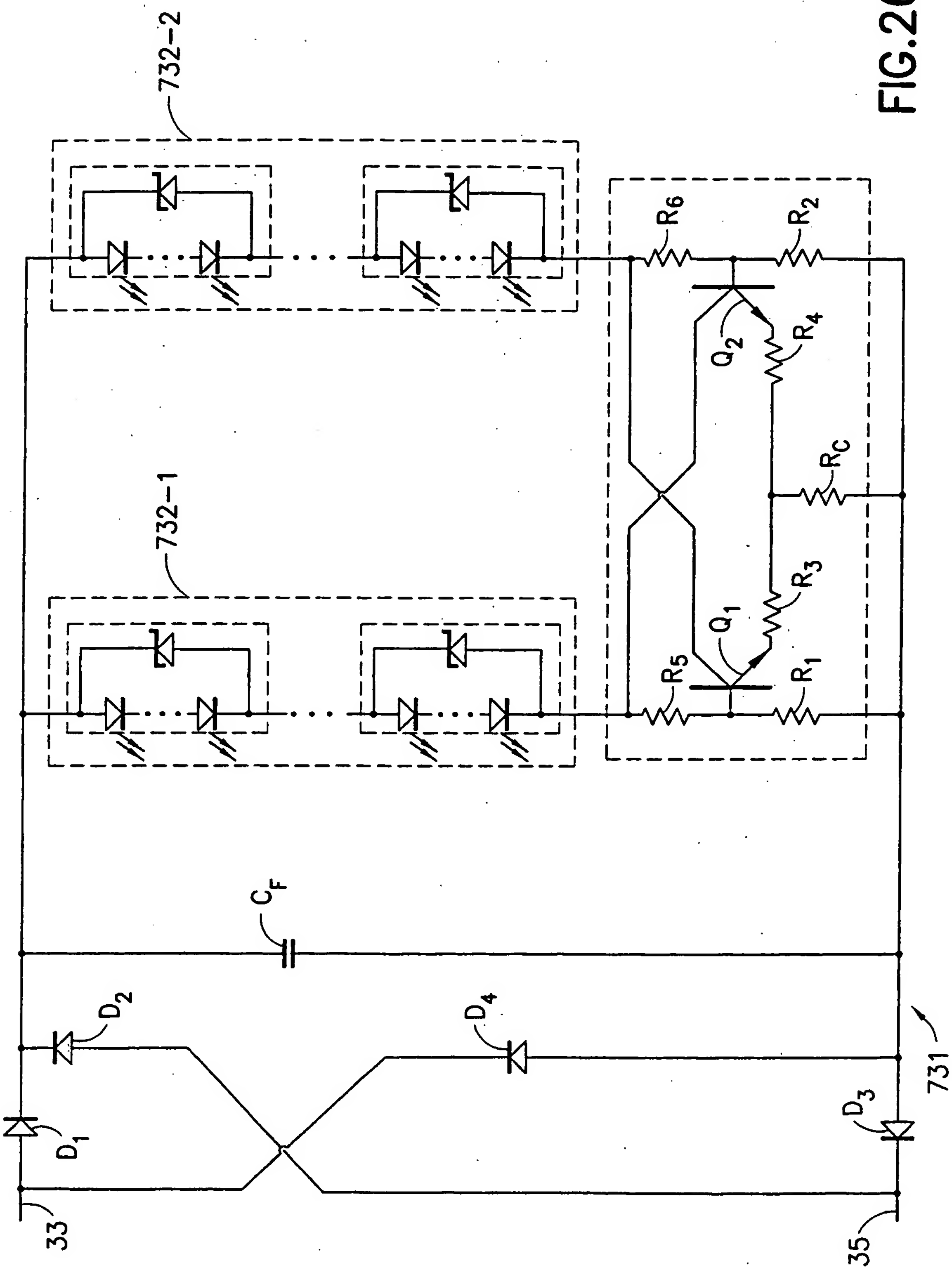


FIG.24

FIG.26



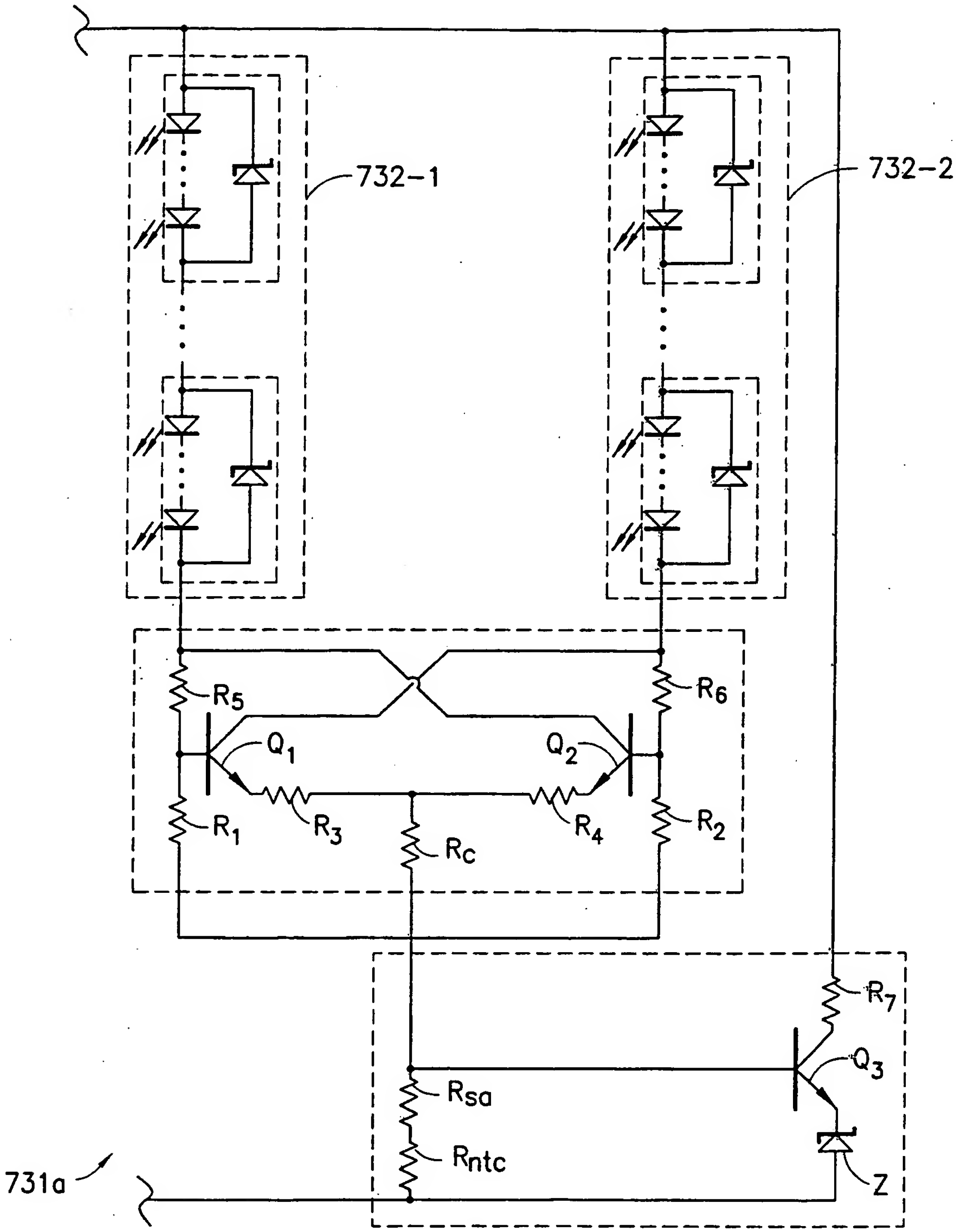


FIG.27

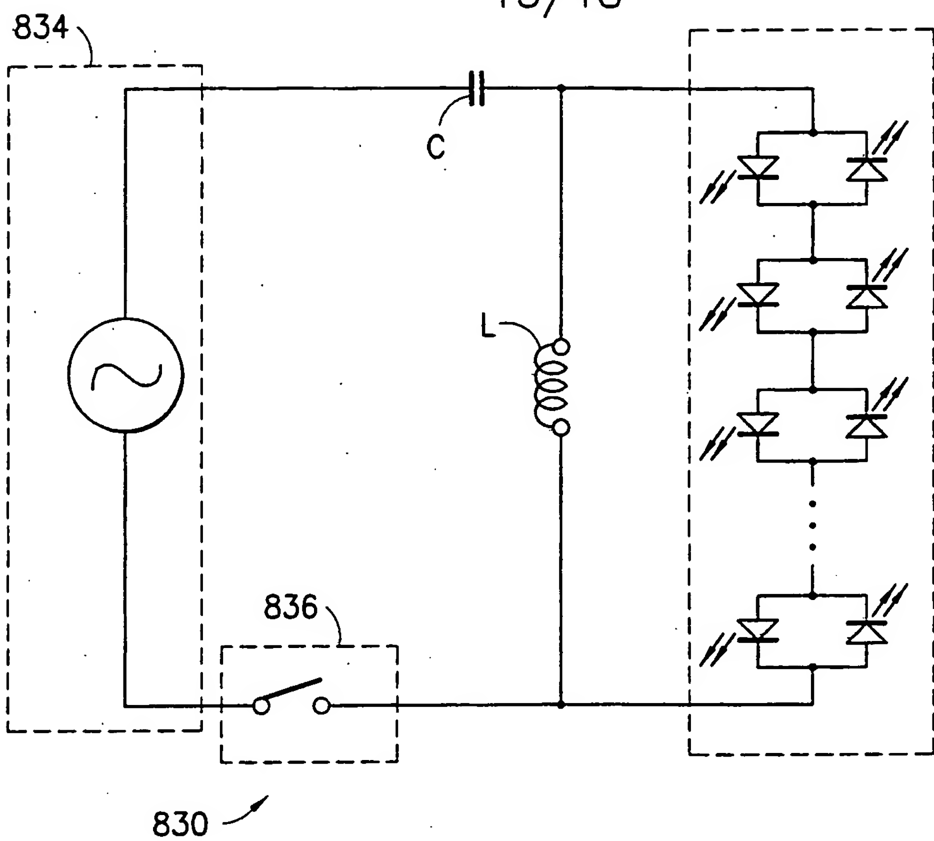


FIG.28

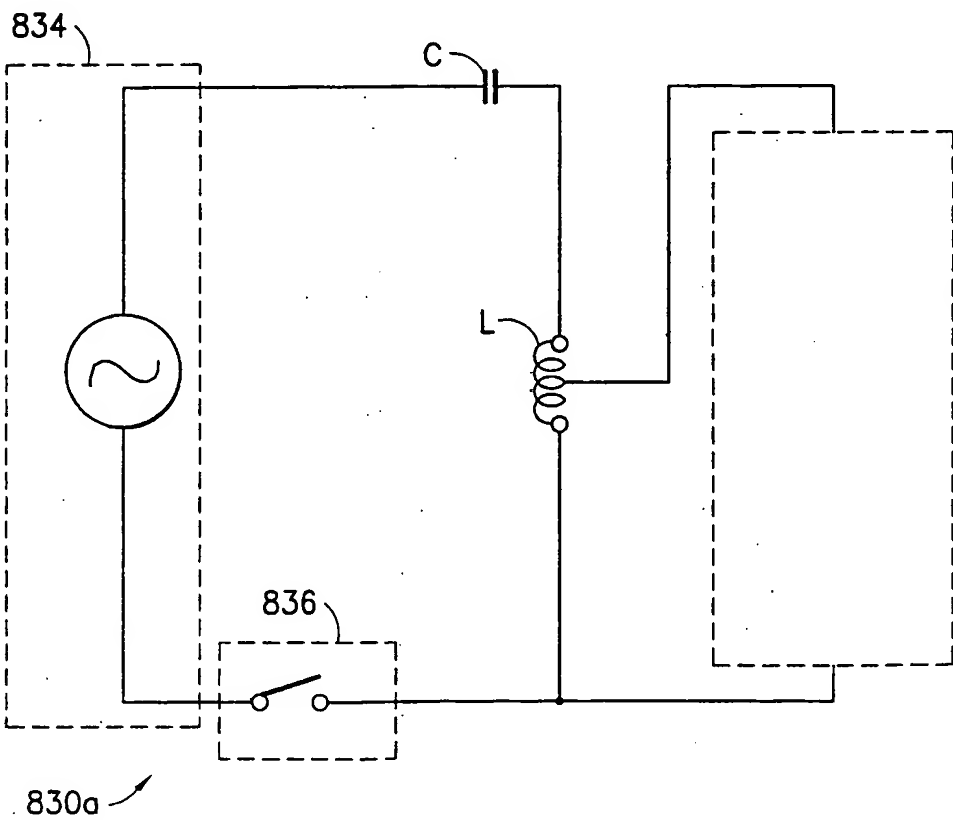


FIG.29

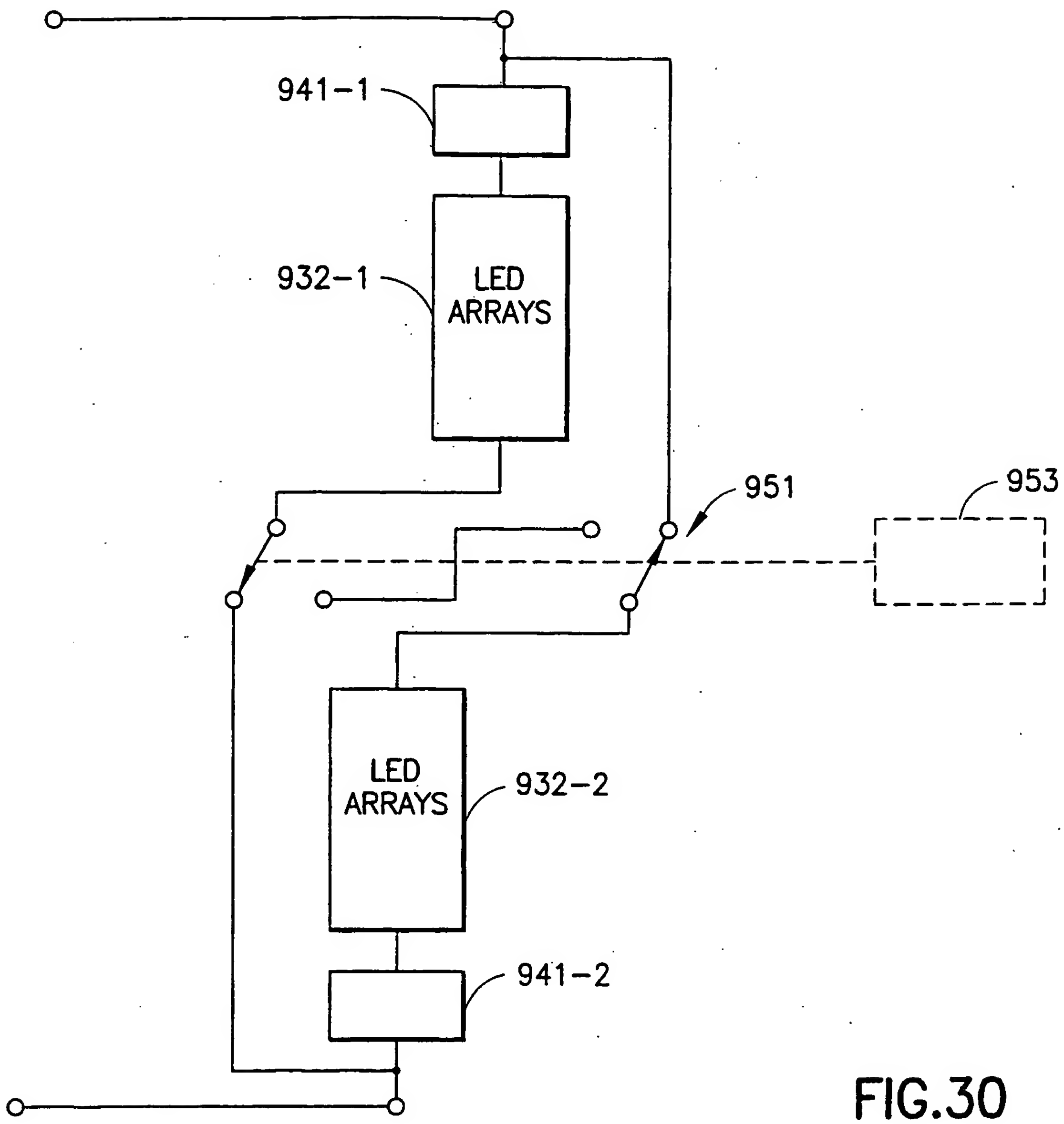

941-1
932-1
LED
ARRAYS
951
953
LED
ARRAYS
932-2
941-2

FIG.30

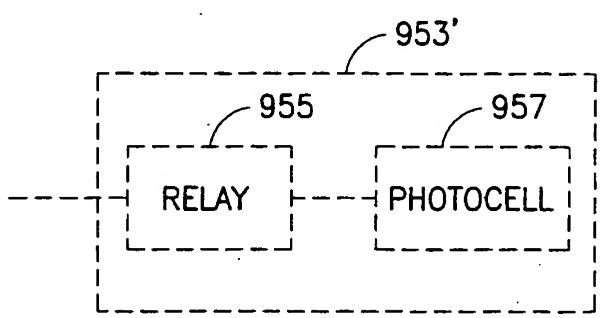

953'
955
957
RELAY
PHOTOCELL

FIG.31

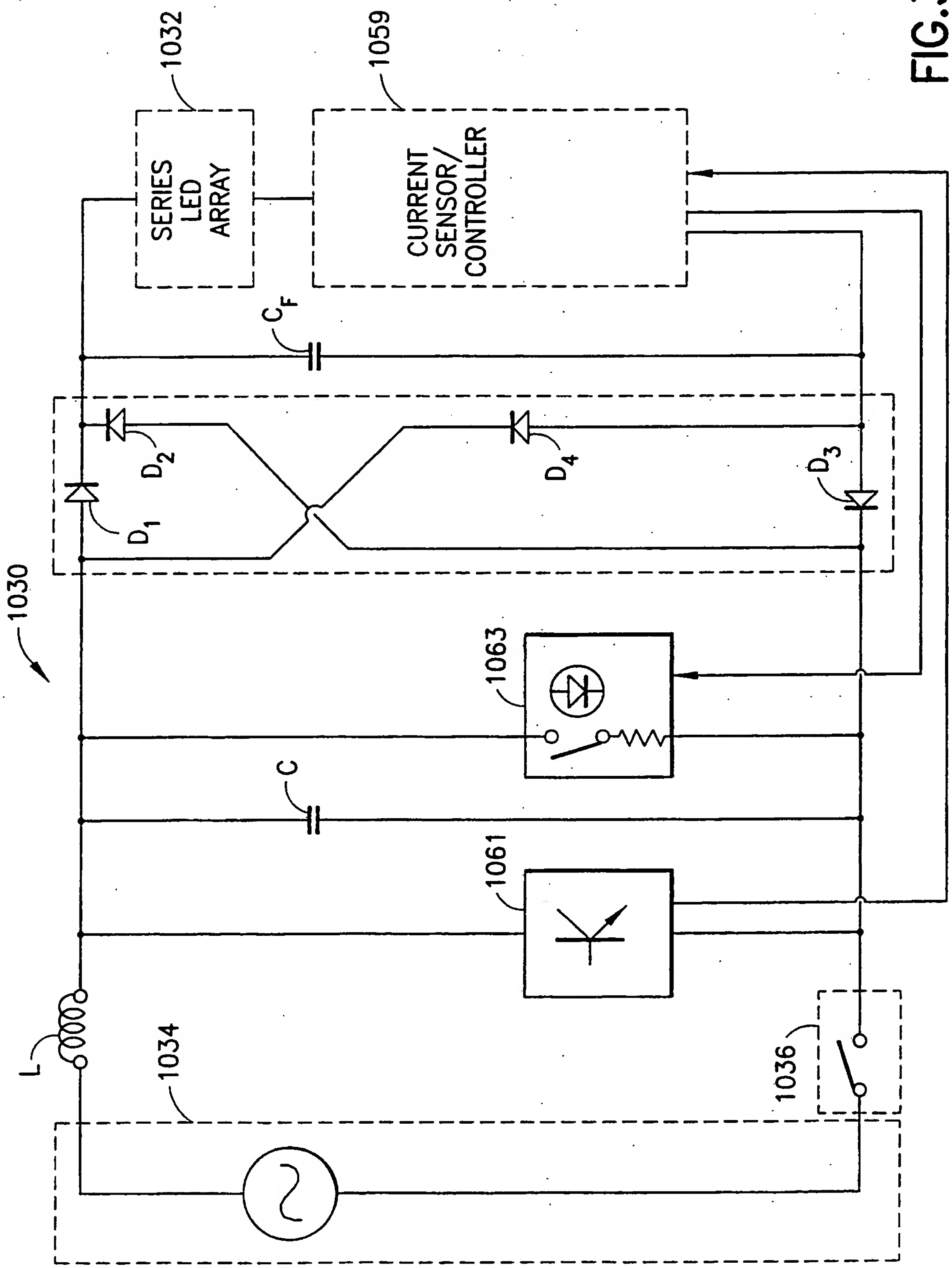

1032
SERIES LED ARRAY
1059
CURRENT SENSOR/ CONTROLLER
C_F
D_1
D_2
D_3
D_4
1030
1063
C
1061
L
1034
1036

FIG.32

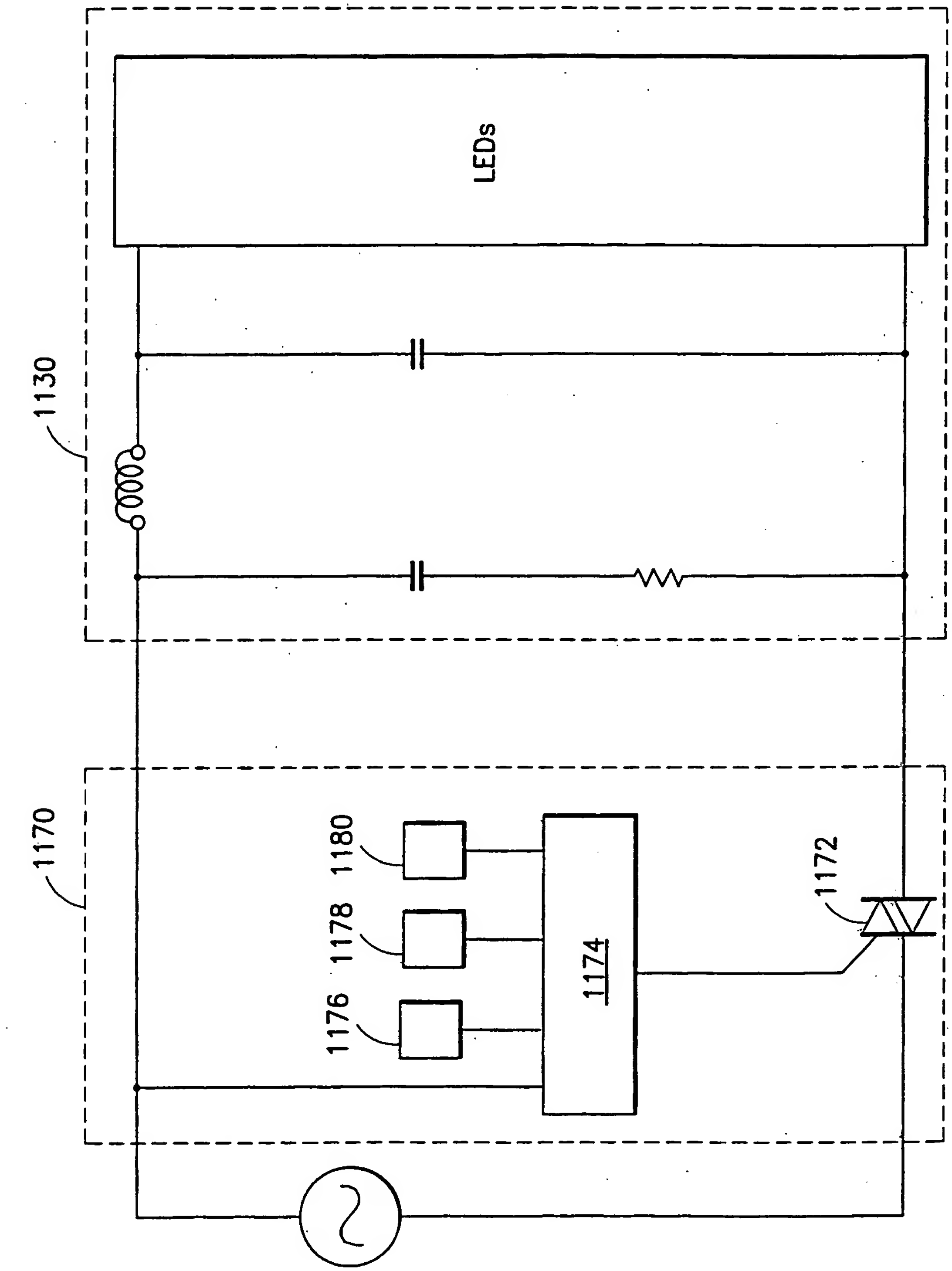


FIG.33

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/14876

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : GO9G 3/36
US CL : 345/46, 82; 345/815.45
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 345/46, 82, 83; 345/815.45; 313/500; 362/800

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,517,500 A (GOTAL ET AL) 14 MAY 1985, FIGURES 1, 4 AND COLUMN 3, LINES 32-38.	20-61
A	US 5,459,478 A (BOLGER ET AL) 17 OCTOBER 1995, FIGURE 1 AND COLUMN 4, LINES 20-24.	31
A	US 3,676,735 A (ROCHE) 11 JULY 1972, FIGURE 1.	1-61
A	US 4,271,408 A (TESHIMA ET AL) 02 JUNE 1981, FIGURES 4, 8, COLUMN 6, LINES 28-55 AND COLUMN 7, LINES 22-33.	1-61
A	US 5,187,377 A (KATOH) 16 FEBRUARY 1993, SEE FIGURE 2.	1-61
A	US 3,869,641 A (GOLDBERG) 04 MARCH 1975, SEE FIUGRE 1.	1-61

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 AUGUST 1999	29 SEP 1999

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/14876

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,321,598 A (WARNER) 23 MARCH 1982, SEE FIGURE 3.	1-61